5G Nation: The UK 5G Ecosystem

Supplementary Information

CATAPULT Digital

This document supports the report ‘5G Nation: the UK 5G Ecosystem 2018’ published by the Digital Catapult in June 2018. The report builds a picture of the UK 5G ecosystem to help drive forward innovation and identify the challenges and opportunities of early adoption of 5G technology in ways that maximise the benefit to the UK economy.

The full report, as well as a database compiling all projects mentions in this supplementary document, can be downloaded from:
https://www.digicatapult.org.uk/projects/5g-mapping

One: Organisations contacted as part of this study

Aberdeen City Council

Advanced Manufacturing Group Warwick

Airbus

Airspan

ARM

Arralis Technologies

ARRIS

AstraZeneca

Avanti Consulting PLC

Bangor University

BBC

Bettis Cadwallader NHS Trust

Blaenau Gwent County Borough Council

Blend Media

Blippar

BOC

Bosch

British Museum

BT PLC

Business Growth Hub

Cardiff Council

Cardiff University

Global VSAT Forum

Greater London Authority

Greater Manchester Combined Authority (GMCA)

GreySky Consulting

GSMA

Gwynedd Council

Helicon Health Limited

Heriot-Watt University

Hobs Studio

Huawei

iDirect

Innovate UK

Innovation Point

Jaguar Land Rover

John Lewis

King's College London

Lancaster University

Livewire Digital

Manchester Metropolitan University

Metaswitch

Milton Keynes Council

Monmouthshire County Council

Salford City Council

Samsung

Satellite Applications Catapult

Scottish Futures Trust

Scottish Government

Sheffield University

Small Cell Forum

Smart Homes and Buildings Association

Sparta Technologies

Spirent Communications

SRS Shared Resource Services

Swansea Bay City Deal

Swansea University

Tameside Metropolitan Borough Council

Telefonica O_2

Telint

The Digital Engineering and Test Centre (DETC)

The Landing

Thomas Cook

Transport for Greater Manchester

UK Manufacturing Association

University College London (UCL)

Carmarthenshire Council

CBNL

CENSIS

CGI IT UK Ltd

Ciena

Cisco Systems

City of Edinburgh Council

Clicks and Links Ltd

Compound Semiconductor Centre

Connected Health Cities/ UoM

Connexin

Cube Ultra

Data Works Wales

Digital Greenwich

DTG

European Space Agency

GeANT

Network Rail

Network Rail Infrastructure Ltd

National Instruments

Nissan

Nokia

North Wales Growth Board

Ocado/Cambridge Consultants

Ordnance Survey

Oxido Limited

Pinnacl

PureLiFi

PWL

QinetiQ Ltd

Quayle

Quintel

Quortus

Royal Opera House

University of Bristol

University of Edinburgh

University of Glasgow

University of Portsmouth

University of Surrey (5GIC)

University of the West of Scotland

Viasat

Warwick Manufacturing Group

Welsh Economy Research Unit

Welsh Government

Wesley Clover Corporation

WHP Telecoms Ltd

Wireless Infrastructure Group

Worcestershire Local Enterprise Partnership

Zeetta

Two: Academic studies focussed on 5G taking place in the UK

The following contains summaries of the 135 academic projects being undertaken by UK institutions in 5G research, detailing

(* Non-UK institutes)

Project Title	MET5G
Lead Organisation	National Physics Laboratory (NPL)
Partners	CZECH METROLOGY INSTITUTE * RISE RESEARCH INSTITUTES OF SWEDEN AB * Chalmers * University of Surrey Anritsu Keysight *
Funding Source	H2020
Funding	N/A
Start / End	01/05/2015 - 31/04/2018
5G Classification Terms	MU-MIMO, Propagation models, mmWave
Weblink	http://empir.npl.co.uk/met5g/
Description (containing objectives, potential outcomes)	The project aims to give EU industries and academia a competitive advantage by providing the essential underpinning metrology for their development of 5G mobile communication platforms. The tasks focus on verifying the system capacity and performance in critical areas where the user density is high. Participation in the standardisation process is essential to maximise impact and to harmonise the test-methods. The specific objectives of the work are to: 1. To define and develop traceable methods to measure Signal-to-Interference-plus-Noise Ratio (SINR) over a wide frequency range – Develop definition(s) of SINR for potential 5G modulation and coding schemes and develop the relevant practical SINR traceable methods to accommodate higher areal density of interference signals. 2. To improve metrology for traceable MIMO antenna systems – The high number of antenna elements and operation at mm-wave frequencies will increase the system test-complexity. The objective is to underpin the development of traceable test methods and algorithms so that efficient and traceable testing is possible. A 5G mm-wave Massive-MIMO testbed will be built and can be made accessible remotely. 3. To develop traceable metrology for 5G mobile

	communication devices – Nonlinearity limits coexistence and ultimately the system capacity. The objective is to place nonlinear measurement using X-parameters and S-functions onto a sound footing, supporting uncertainty relationships and model extraction parameters (e.g. for nonlinear behavioural models) and proven by inter-comparison with other users worldwide. This will include validation of new nonlinear test methods for application at mm-wave frequencies. 4. To engage with industries that manufacture 5G mobile communication technology – The measurement infrastructure developed by the project will be used to support the development of new, innovative products, demonstrating the benefit of metrology in improving the take-up of the technology and enhancing the competitiveness of EU industry.

Project Title	iCIRRUS: intelligent Converged network consolidating Radio and optical access around user equipment
Lead Organisation	UNIVERSITY OF KENT
Partners	ADVA OPTICAL NETWORKING LIMITED ORANGE SA * TELEKOM SLOVENIJE DD * PRIMETEL PLC * WELLNESS TELECOM SL * FRAUNHOFER GESELLSCHAFT ZUR FOERDERUNG DER ANGEWANDTEN FORSCHUNG E.V. * UNIVERSITY OF ESSEX VIAVI SOLUTIONS UK LIMITED IAF INSTITUT FUER ANGEWANDTE FUNKSYSTEMTECHNIK GmbH * INTERDIGITAL EUROPE LTD ADVA OPTICAL NETWORKING SE *
Funding Source	H2020
Funding	€ 3,832,195
Start / End	01/01/2015 - 31/12/2017
5G Classification Terms	Optical Network, Cloud RAN, D2D, Antenna, NFV
Weblink	http://www.icirrus-5gnet.eu/
Description (containing objectives,	To meet the high throughput demands envisaged for 5G networks, with increased user densification and bandwidth-hungry applications, while at the same time reducing energy consumption, iCIRRUS

potential outcomes)	proposes an intelligent Cloud-Radio Access Network (C-RAN) that brings together optical fibre technology, low-cost but highly flexible Ethernet networking, wireless resource management for device-to-device (D2D) communication (incl. the use of mm-wave spectrum) and the use of virtual mobiles in the cloud. The iCIRRUS C-RAN introduces the use of Ethernet in the fronthaul/midhaul (for radio signal transport), to minimise cost and make available pluggable and in-device monitoring, and intelligent processing to enable self-optimizing network functions which maximise both network resource utilisation and energy efficiency. To exemplify the attractiveness of the proposition, iCIRRUS focusses on D2D communication in the wireless domain, an important work area in current standardisation, where low latency is known to be a significant factor. The latency and jitter in the iCIRRUS Ethernet-based C-RAN will be an important focus of the research work in the project, with current 5G performance targets in mind; for D2D communications, the task will be to minimise control latency and overhead. A major obstacle for C-RANs is the bit-rate of the digitised radio signals that would be required for 5G – of the order of 100 Gb/s and iCIRRUS will examine the architectural and technological questions surrounding this requirement. Wireless resource management will be investigated, together with mobile device caching and mm-wave D2D mesh networks, to reduce latency as well as load on the infrastructure. Finally, the intelligent network functions in ICIRRUS can interact with mobile cloud processing, and further offloads of infrastructure communications can be realised through virtualising mobiles in the cloud as clones, and performing communication tasks between clones.

Project Title	5GCITY
Lead Organisation	FUNDACIO PRIVADA I2CAT, INTERNET I INNOVACIO DIGITAL A CATALUNYA *
Partners	NEC EUROPE LTD VIRTUAL OPEN SYSTEMS * PRISMTECH FRANCE * RETEVISION I, S.A. * UNIVERSITY OF BRISTOL NEXTWORKS * COMUNE DI LUCCA * ITALTEL SPA * INSTITUT MUNICIPAL D'INFORMATICA DE BARCELONA * MOG TECHNOLOGIES SA *I WIND TRE SPA * RAI-RADIOTELEVISIONE ITALIANA SPA * UBIWHERE LDA * INFORMACIO I COMUNICACIO DE BARCELONA SA SOCIETAT PRIVADA MUNICIPAL * INCITES CONSULTING SARL *

	ACCELLERAN * COMUNICARE DIGITALE - ASSOCIAZIONEDI PROMOZIONE SOCIALE *
Funding Source	H2020 (5G-PPP)
Funding	€ 6,072,367.40
Start / End	01/06/2017 - 30/11/2019
5G Classification Terms	MEC (Mobile Edge Computing), Cloud RAN, Network Slicing, Network Automation, Media (AR/VR), IoT - Smart Cities
Weblink	https://www.5gcity.eu/
Description (containing objectives, potential outcomes)	Delivering on the 5G promise of increased data rates, and ubiquitous coverages, poses stringent requirements on traditional vertically integrated operators. In particular, telecom operators are expected to massively roll out Small Cells, which requires finding appropriate urban spaces with both backhaul and energy availability. Network sharing becomes essential to unlock those commercial massive deployments. The open access model, or neutral host, will come to play a key role on the deployment of 5G networks, especially in urban scenarios where very dense Small Cell deployments are required. In parallel recent trends are paving the way towards the development of new, heterogeneous and distributed cloud paradigms that significantly differ from today's established cloud model: with edge computing, cloud architectures are pushed all the way to the edge of the network, close to the devices that produce and act on data. We posit that there are two sets of players perfectly poised to take advantage of both trends since they already own the infrastructure needed to build edge deployments: telecommunication providers and municipalities. 5GCity focuses on how common smart city infrastructure (i.e., small cells and processing power at the very edge of networks) can bring benefit to both players based on resource sharing and end-to-end virtualization, pushing the cloud model to the extreme edge. 5GCity will design, develop, deploy and demonstrate a distributed cloud and radio platform for municipalities and infrastructure owners acting as 5G neutral hosts. 5GCity's main aim is to build and deploy a common, multi-tenant, open platform that extends the (centralized) cloud model to the extreme edge of the network, with a demonstration in three different cities (Barcelona, Bristol and Lucca). 5GCity will directly impact a large and varied range of actors: (i) telecom providers; (ii) municipalities; and (iii) a number of different vertical sectors utilizing the city infrastructure.

Project Title	Vehicular Ad-hoc Networks

Lead Organisation	Loughborough University
Partners	University of Colima (Mexico) *
Funding Source	N/A
Funding	N/A
Start / End	N/A
5G Classification Terms	Automotive, HetNets, Routing
Weblink	http://www.lboro.ac.uk/research/5grc/researchprojects/currentprojects/vehicular-ad-hoc-networks.html
Description (containing objectives, potential outcomes)	The aim of this research is to reduce congestion by improving large scale traffic flow on busy highways. A proportion of road users will be advised by an in-car device of the optimal speed for them which in turn will optimise the speed of all the cars in their immediate area. Compliance reduces the drivers' road/toll tax. An example of the implementation of a related system is that of the London Congestion Charge that in its first year of operation (2003) reported traffic reductions of 25%. In this system a percentage of vehicles (research) will dictate the flow characteristics of all vehicles on the highway. A large scale vehicular ad-hoc network is needed and upon that network an algorithm run to advise drivers. Future work involves the manufacture of the speed advice device and the choice of suitable machine learning algorithms for voluntary linear flow of vehicles. Loughborough University (UK) will research the radio part whilst the University of Colima, Mexico, will research the ad-hoc network. All partners will integrate and develop the system. The work at Loughborough will initially consider a 4G/5G backbone over an 802.11 family local vehicular ad-hoc network. Software defined radio may be used.

Project Title	Flood Prediction using real time sensing Emergency Water Information Networks over mobile phone networks and Wi-Fi (EWIN)
Lead Organisation	Loughborough University

Partners	Dynamic Flow Technology Ltd (DFTL) Siteldi
Funding Source	EPSRC
Funding	£ 1,485,560
Start / End	01/05/2017 -30/04/2020
5G Classification Terms	HetNets, Other
Weblink	http://gow.epsrc.ac.uk/NGBOViewGrant.aspx?GrantRef=EP/P029221/1
Description (containing objectives, potential outcomes)	We are working on ways to monitor flooding in real time using remote water sensing over cellular phone systems. With the predicted impacts of climate change flooding will be a global problem. Minutes of advance warning are important and modern flood warning systems are critical for a country to protect its people and develop and grow its towns and cities. Flooding is the most serious of natural disasters mankind has to cope with in terms of loss of life and the long term effects of flooding have severely adverse social consequences. Unlike the UK that has a mature flood defence system, many countries have not been able to afford the technology and have poor response to flooding. However, many developing countries do now have access to modern cellular phone networks in their towns and cities. So in this project we will discover how to use mobile phone networks combined with Wi-Fi to help countries tackle climate change. Two teams of researchers from the UK and Mexico, supported by small companies with experts in the fields of water engineering and embedded electronics have come to together to investigate how real time flood monitoring can be done over modern phone systems to provide modern water engineering infrastructure in a cost effective way to quickly make countries vulnerable to flooding more resilient to this most serious of natural disasters. To improve flood prediction several areas of research need to be addressed. Concisely, the data for real time flood prediction needs be sensed in the right place and at the right time, transmitted in harsh conditions, fused in the cloud and used to make reliable flood prediction models. Our research addresses each of these areas using UK expertise in Water Engineering and Radio Communications to complement Mexican knowledge of Water Engineering, Data Networks and Enterprise. At the end of the project we will have measured parts of and modelled a complete flood prediction network for Mexico and in the process understood how water behaves before, during and after flooding. Mexico is a country of extremes with a dry season where hardly any rain falls and rainy season with volumes of water in rivers unseen in the UK. For the UK

	climate change is predicted to mean more dynamic and intensive large scale weather effects so there are significant benefits the United Kingdom as well as Mexico and many other countries. Combined with background research, prototyping of sensors packages and waterway modelling, our teams will be conducting a series of highly targeted field trials - small scale in the UK where rivers and lakes and relatively predictable and medium scale in Mexico where we will seek flood events to be studied in real time. Two new exciting water sensing technologies, one that uses Doppler radar and another that using similar techniques to face recognition will be used for the first time in this work to detect the water conditions prior and during a flood event. The two techniques are special because they do not need to be in the water and are therefore much harder to wash away than traditional sensors. We intend to use a portable system that can be deployed quickly in areas that may flood to give much needed advanced warning and monitor water levels during the time before the water recedes.

Project Title	Frequency Agile Radio (FARAD)
Lead Organisation	University of Sheffield
Partners	University of Bristol Cascoda Limited Chemring Technology Solutions Fujitsu Harada Industries (Europe) Ltd Mobile VCE NEC Orange Corporate services Limited Thales Ltd u-blox UK Ltd
Funding Source	EPSRC
Funding	£ 1,235,854
Start / End	01/04/2015 - 31/12/2018
5G Classification Terms	Antenna, Radio Front-end / RF, HetNets
Weblink	http://gow.epsrc.ac.uk/NGBOViewGrant.aspx?GrantRef=EP/M013723/1 http://gow.epsrc.ac.uk/NGBOViewGrant.aspx?GrantRef=EP/M01360X/1

Description (containing objectives, potential outcomes)	Wireless communications has become a pervasive technology that we use throughout our lives. Across society, there is a move away from using the internet on desktop computers and towards smartphones, tablets and laptops. Consequently, the amount of wireless data transmission to support our online activities is rapidly increasing. There is also significant growth in automatic data sharing and collection from many types of sensors, meters and embedded computers, sometimes referred to as machine-to-machine (M2M) communications. This continuing growth in mobile data is a significant problem for network operators. In order to meet this enormous traffic growth challenge, operators are considering a number of potential solutions with three leading concepts: 1. increasing the availability of radio spectrum; 2. deploying heterogeneous and small cell networks; and 3. separating control and traffic data for enhanced network management. This project will address the expected capacity crunch by focusing on the RF bottleneck in future heterogeneous wireless networks through researching and developing miniature, integrated, reconfigurable and tuneable, multiband radios to enable 'spectrum agile' radio access and concurrent multiband operation. Research will address the radio system agility across the microwave spectrum bands from 450 to 6000 MHz. The project will embrace the co-design of antennas, amplifiers, filters and digitisers to achieve spectrum and energy efficient frequency agile radio systems. The project consists of five major research areas: 1. Tuneable Antennas and Filters - Research will focus on reconfigurable and tuneable antennas with integrated filters to achieve frequency selectivity and concurrent multiband operation. 2. Transmit Amplifiers - Research on transmit amplifiers for base stations and handsets will focus on methods to achieve re-tuneable, linear, wideband, power efficient and concurrent multiband operation. 3. Receiver Interference Mitigation - Simple and efficient solutions to reduce the effects of unwanted signal suppression caused by RF blockers in the multiband RF receiver chain will be sought. 4. Multiband A/D Conversion & PAPR Reduction - Research will focus on developing concurrent multiband ADC techniques at the receiver and the design of signal sets with significantly reduced peak-to-average-power ratio (PAPR). 5. Testbed Demonstration: Themes 1-4 will lead to the evaluation and demonstration of solutions using a hardware-in-the-loop RF testbed. By researching a frequency agile, concurrent multiband radio technology FARAD will significantly contribute to the growth of future radio access networks and the use of new spectrum bands in an efficient way. The techniques and algorithms developed in this project will enable far reaching capabilities in wireless networks for the next 20 to 30 years helping to solve the anticipated capacity crunch while establishing a new paradigm in radio transceiver design.

Project Title	M2WPT - a large-scale Multi-antenna Multi-sine Wireless Power Transfer architecture

Lead Organisation	Imperial College London
Partners	Eindhoven University of Technology * Home Office Keysight Technologies UK Ltd KU Leuven * Toshiba
Funding Source	EPSRC
Funding	£ 676,973
Start / End	01/01/2017 - 31/12/2019
5G Classification Terms	Massive / MU-MIMO, Antenna, Propagation / Channel Modelling, Baseband/ Signal processing
Weblink	http://gow.epsrc.ac.uk/NGBOViewGrant.aspx?GrantRef=EP/P003885/1
Description (containing objectives, potential outcomes)	Wireless power transfer (WPT) via radio-frequency (RF) radiation has long been regarded as a possibility for energising low-power devices in the internet of things. It is, however, not until recently that WPT has become recognised as feasible, due to reductions in power requirements of electronics. Far-field WPT using RF could be used for long range power delivery to increase user convenience. In the same way as wireless disrupted communication, WPT using RF is expected to disrupt the delivery of energy. The real challenge with far field WPT is to find ways to increase the DC power level at the energy harvester output without increasing the transmit power, and to ensure that sufficient range between transmitter and receiver can be achieved. The project relies on the observation that far-field WPT RF-to-DC conversion efficiency is a function of the antenna design but also of its input waveform. A proper design of far-field WPT therefore requires a complete transmitter-receiver optimization rather than just the receiver (rectenna) design. Unfortunately state of the art waveforms have been shown partially disappointing for far-field WPT. The fundamental question behind the project is "can we design a disruptive but practical WPT transceiver architecture to make wireless power transfer a reality at distances of tens (if not more) of meters within regulated transmit power levels?" This visionary project, conducted at Imperial College London, will uniquely leverage signal processing tools to tackle a problem commonly investigated by the RF community. Motivated by recent results by the PI and Co-I and leveraging a unique set of complementary skills on multi-

	antenna signal processing (Clerckx) and WPT/rectenna design (Mitcheson), the project will design and show the feasibility of a disruptive M2WPT architecture based on optimized, adaptive and reliable large-scale multi-antenna multi-sine waveforms for single-user and multi-user scenarios, and identify its potential for far-field WPT. Thinking big, we advocate in this project that M2WPT will be to WPT what massive MIMO is to communication. M2WPT will enable highly efficient far-field WPT delivering sufficient power at long range for a wide range of applications. To put together this novel M2WPT solution in a credible fashion, this project focuses on 1) designing and modelling the energy harvester, 2) designing large-scale multi-sine multi-antenna waveforms for single and multi-user scenarios, 3) demonstrate the feasibility through experiment and measurement. The project will be performed in partnership with two leaders in equipment manufacturing and WPT standardization (Toshiba and Keysight), two well-established academic/research centres active in WPT (KULeuven and Eindhoven/IMEC) and the UK Office of the Chief Science Adviser. The project demands a strong and inter-disciplinary track record in microwave theory and techniques, circuit design, optimization theory, multi-antenna signal processing, wireless communication and it is to be conducted in a unique research group with a right mix of theoretical and practical skills. With the above and given the novelty and originality of the topic, the research outcomes will be of considerable value to transform the future of wireless networks supplied by remote wireless charging and give the industry a fresh and timely insight into the development of highly efficient remote wireless charging, advancing UK's research profile of wireless power in the world. Its success would radically change the design of radiative WPT, have a tremendous impact on standardization, and applications in a large number of sectors including building automation, healthcare, telecommunications, ICT, structural monitoring, consumer electronics.

Project Title	iBROW: Innovative ultra-BROadband ubiquitous Wireless communications through terahertz transceivers
Lead Organisation	UNIVERSITY OF GLASGOW
Partners	VIVID COMPONENTS LTD ALCATEL-LUCENT DEUTSCHLAND AG * UNIVERSIDADE DO ALGARVE * IQE Silicon Compounds Ltd III-V LAB * COMPOUND SEMICONDUCTOR TECHNOLOGIES GLOBAL LIMITED TECHNISCHE UNIVERSITAET BRAUNSCHWEIG * COMMISSARIAT A L ENERGIE ATOMIQUE ET AUX ENERGIES ALTERNATIVES *

	INESC TEC - INSTITUTO DE ENGENHARIA DE SISTEMAS E COMPUTADORES, TECNOLOGIA E CIENCIA * Optocap Ltd
Funding Source	H2020
Funding	€ 3,995,128.75
Start / End	01/01/2015 - 30/06/2018
5G Classification Terms	Radio Front-end / RF, Baseband/ Signal processing, mmWAVE
Weblink	http://ibrow-project.eu/
Description (containing objectives, potential outcomes)	The demand for broadband content and services has been growing at tremendous rates, and predictions indicate that wireless data-rates of multiple tens of Gbps will be required by the year 2020, essentially for short-range connectivity. Currently available wireless technology cannot support these future demands, and so there is an urgent need to develop new technology platforms that are cost and energy efficient to enable ubiquitous ultra-broadband wireless communications seamlessly integrated with high-speed fibre-optic networks, paving the way for 100 Gbps data rates in the long term. The frequency spectrum currently in use is not expected to be suitable to accommodate the predicted future data-rate requirements, and therefore there is a need to embrace higher frequency bands, above 60 GHz and up to 1 THz. iBROW aims at developing a novel, low cost, energy-efficient and compact ultra-broadband short-range wireless communication transceiver technology, capable of addressing predicted future network usage requirements. This will be pursued through the exploitation of Resonant Tunnelling Diode (RTD) devices which represent the fastest pure solid-state electronic devices operating at room temperature with reported working frequencies exceeding 1 THz. Through the development of a unified technology that can be integrated into both ends of the wireless link, namely consumer portable devices and fibre-optic supported base-stations, the project aims at increasing the RTD output power, optical detection efficiency and energy efficiency at target frequencies, developing a methodology for low cost RTD manufacturing on a silicon platform, photonic integration and packaging, as well as identifying appropriate communication methods and architectures to enable its deployment in 10 Gbps short-range wireless communication devices in short term and paving the way for 100 Gbps in long term for both the mm-wave and THz frequency bands, seamlessly integrated with optical fibre networks

Project Title	Clear5G: Converged wireless access for reliable 5G MTC for factories of

	the future
Lead Organisation	University of Surrey
Partners	ADLINK TECHNOLOGY INC * ARGELA YAZILIM VE BILISIM TEKNOLOJILERI SANAYI VE TICARET AS * COMMISSARIAT A L ENERGIE ATOMIQUE ET AUX ENERGIES ALTERNATIVES * FAIR FRIEND ENTERPRISE CO., LTD * HON HAI PRECISION INDUSTRY CO, LTD * Institute for Information Industry * NATIONAL TAIWAN UNIVERSITY * NEDERLANDSE ORGANISATIE VOOR TOEGEPAST NATUURWETENSCHAPPELIJK ONDERZOEK TNO * TOSHIBA RESEARCH EUROPE LIMITED TURK TELEKOMUNIKASYON AS * WINGS ICT SOLUTIONS INFORMATION & COMMUNICATION TECHNOLOGIES EPE *
Funding Source	H2020
Funding	€ 2,498,616.25
Start / End	01/09/2017 - 29/02/2020
5G Classification Terms	IoT - Industry 4.0, MAC / RRM, NB-IoT, HetNets, Baseband/ Signal processing
Weblink	https://cordis.europa.eu/project/rcn/211422_en.html
Description (containing objectives, potential outcomes)	Clear5G's objective is to design, develop, validate, and demonstrate an integrated convergent wireless network for Machine Type and Mission Critical Communication (MTC/MCC) services for Factories of the Future (FoF). Clear5G will deliver technical solutions addressing the challenges of massive deployment of connected devices, security, ultra-low latency and ultra-high reliability in FoF applications, like remote maintenance and closed loop control systems. The requirements of these complex scenarios will be met through the convergence of different wireless technologies, enabled by protocol and architecture enhancements proposed by Clear5G. Clear5G will focus on providing PHY, MAC, and architectural enhancements to meet the strict requirements of FoF applications in terms of KPIs: latency, reliability, connection density, spectrum, and energy efficiency, thus contributing to the ITU-R objectives (e.g. 1000 fold connection density) for the next generation mobile network. The Clear5G team comprises a combination of European and Taiwanese successful, innovative, and well known major corporations, SMEs, as well as research and academic institutions. The partners have proven know-how in architecture, resource management, protocol

	enhancements, standardization, prototyping, and demonstration. Proof of concepts will be tested on the 5GIC testbed in Europe, while the final system demonstration, showing the tight integration and cooperation of manufacturing and the Clear5G enhanced network, will be implemented on the III testbed in Taiwan. Clear5G brings together a strong and diverse set of European and Taiwanese partners, including partners from the FoF sector; the complementarity of team, skills and expertise will bring added value to 5G research on both sides and will deepen international cooperation, serving as a showcase of 5G empowering vertical industries. The partners will contribute to relevant standardisation in both the communication and the manufacturing domains.

Project Title	Modelling, analysis and strategies for beyond next generation vehicular heterogeneous wireless networks
Lead Organisation	University of York
Partners	N/A
Funding Source	N/A
Funding	N/A
Start / End	01/2015 - 12/2017
5G Classification Terms	QoS/QoE, Automotive, MAC / RRM
Weblink	https://www.york.ac.uk/electronic-engineering/research/communication-technologies/projects/vehicular-heterogenous-wireless-networks-ai/
Description (containing objectives, potential outcomes)	5G and beyond communication systems will have challenging requirements for data rate, energy efficiency and end-to-end latency especially for the users on the move. The dynamic mobile communication network involves multi-service demand such as voice, data or video in multi-environment scenario. The scenario further encompasses broad variation in user mobility from pedestrians to slow and fast vehicular mobile users. To test and analyse all these challenges, conventional distributed integrated small cell network infrastructure is deployed over a high mobility micro-cellular vehicular with and without interrupted flow environment. The research aims are to understand and establish strong link between user experience and highly dynamic vehicular environment through analysis of application of learning techniques. Strategies could include machine learning and other artificial intelligence approaches. The purpose of the project will be to show how, by applying these forms of artificial intelligence, it is possible to improve the performance of the cell selection, resource and topology management algorithms. The learning schemes and strategies which will be developed are

	believed to have the capability to achieve significantly low latency, high throughput performance to the vehicular users.

Project Title	Radio Resource Allocation in Beyond Next Generation Wireless Systems
Lead Organisation	University of York
Partners	N/A
Funding Source	N/A
Funding	N/A
Start / End	02/102
5G Classification Terms	MAC/RRM, Energy Efficiency
Weblink	https://www.york.ac.uk/electronic-engineering/research/communication-technologies/projects/radio-resource-allocation
Description (containing objectives, potential outcomes)	The demand for mobile traffic is estimated to increase exponentially in future wireless networks. Hence, these networks will require denser deployment of base stations, which can potentially lead to significant increase in energy consumption, to meet the estimated high traffic demand. As a result, beyond next generation wireless systems will be expected to deliver high data rates and ultra-high capacity density in an energy efficient and environmentally friendly manner. In this project, radio resource allocation and topology management schemes will be developed and evaluated in order to achieve the goals of high capacity density and energy efficiency for beyond next generation wireless networks. These schemes will aim to reduce energy consumption in the network when traffic level is not optimum by adjusting the number of active base stations in accordance with the traffic load and mitigating interference. The schemes will also apply different degrees of cognition so that nodes in the network can learn about their surrounding environments and make informed decisions based on the knowledge acquired. Both simulation and analytical techniques, such as game theory and queuing theory, will be employed in the evaluation of the performances of developed schemes. This project will be integrated with other activities going on within the group.

Project Title	Artificial Intelligence in Cognitive and Green Radio: Lessons from Control Engineering

Lead Organisation	University of York
Partners	N/A
Funding Source	N/A
Funding	N/A
Start / End	10/2012
5G Classification Terms	MAC/RRM
Weblink	https://www.york.ac.uk/electronic-engineering/research/communication-technologies/projects/ai-cognitive-green-radio/
Description (containing objectives, potential outcomes)	The main aim of this project is to establish a strong link between cognitive communications and control engineering through analysis of applications of artificial intelligence (AI) in both fields. This link could be used to utilise the knowledge and experience of control engineering community to improve the reliability and effectiveness of AI methods applied to various aspects of cognitive and green communications. The application areas of primary concern in this project are dynamic radio resource and topology management. The results of investigating these particular areas aim to contribute to the EU FP7 ABSOLUTE project. Many other aspects of cognitive and green communications, as well as control engineering, could also potentially benefit from successful establishment of the link between the two fields

Project Title	Software Defined Networking for Next Generation Communications
Lead Organisation	University of York
Partners	NEC
Funding Source	FP7
Funding	Funded through CROSSFIRE
Start / End	01/2013 - NA
5G Classification Terms	SDN, MAC/RRM, HetNets
Weblink	https://www.york.ac.uk/electronic-engineering/research/communication-technologies/projects/software-defined-netowrking/
Description (containing objectives,	As wireless traffic continues to grow, network operators must carry higher volumes of data and support more sophisticated services. To meet the rising and diverse user demands, further improvement in

potential outcomes)	wireless communication technology is required to enhance service delivery for example, through higher data rates, low latency, reduced interference and even greater capacity. The increasing heterogeneity in either access technology, topological layers for example, macro, pico, femto or spectrum (multiple frequency bands, maybe aggregated) has made it necessary for operators to maintain and operate distinct access, backhaul and core networks. This could lead to increased OPEX and CAPEX for the operators. Furthermore, network operators need flexible deployment capabilities to migrate from older to newer technologies without impacting the end user experience. Therefore, to address these challenges a holistic approach is required that leverages the strength of software defined networking (SDN) with the help of virtualization as enabling technology to transform the way networks are managed at present and adapt network operations based on real time traffic behaviour. This approach should simplify network management, enable network resource sharing and provide flexibility to introduce new and innovative services in a short time. This project forms part of CROSSFIRE- (unCooRdinated netwOrk StrategieS for enhanced interFerence, mobility, radio Resource, and Energy saving management in LTE-Advanced networks) is a Multi-Partner Initial Training Network (MITN) Marie Curie project that is focused on providing forward-looking solutions for Long Term Evolution-Advanced (LTE-A) network co-existence including aspects ranging from the physical layer such as co-channel interference and cognition to the user perception of the service, i.e., Quality of Experience (QoE). The project will analyse and propose network virtualization solutions for LTE-A networks, a technology which is envisioned to transform operation of cellular networks in the years to come.

Project Title	Network Coded Modulation for Next Generation Wireless Access Networks
Lead Organisation	University of York
Partners	University of Reading BT Fujitsu Vodafone
Funding Source	EPSRC
Funding	£ 990,667
Start / End	18/11/2013 - 31/07/2017
5G Classification Terms	MAC/RRM
Weblink	https://www.york.ac.uk/electronic-

	engineering/research/communication-technologies/projects/net-cod-mod-5g/
Description (containing objectives, potential outcomes)	In view of the rapid increase in demand for mobile data services, next generation wireless access networks will have to provide greatly increased capacity density, up to 10 Gbps per square kilometre. This will require a much larger density of very small, cheap and energy-efficient base stations, and will place increasing demand on the bandwidth and energy efficiency of the network, and especially the backhaul network. Recent work on network MIMO, or coordinated multipoint (CoMP) has shown that by ensuring base stations cooperate to serve users, especially those close to cell edge, rather than interfering with one another, inter-user interference can be effectively eliminated, greatly increasing the efficiency of the network, in terms of both spectrum and energy. However this tends to greatly increase the backhaul load. This work proposes a form of wireless network coding, called network coded modulation, as an alternative to conventional CoMP. This also enables base station cooperation, but instead of sending multiple separate information flows to each base station, flows are combined using network coding, which in principle allows cooperation with no increase in backhaul load compared to non-cooperative transmission, while gaining very similar advantages to CoMP in terms of bandwidth and energy efficiency. The objective of the proposed work is to establish the practical feasibility of this approach, and evaluate its benefits, as applied to next generation wireless access networks. To this end it will develop practical signalling schemes, network coordination and management protocols, and, with the help of industrial collaborators, will ensure compatibility with developing wireless standards.

Project Title	Resource and Topology management for 5G systems
Lead Organisation	University of York
Partners	N/A
Funding Source	N/A
Funding	N/A
Start / End	10/2013 - N/A
5G Classification Terms	SDN, Energy Efficiency, MAC / RRM
Weblink	https://www.york.ac.uk/electronic-engineering/research/communication-technologies/projects/resource-topology-management-5g/

Description (containing objectives, potential outcomes)	This project will explore how resource and topology management should be controlled in future 5G networks. Such networks will need to be highly adaptive to deal with hot spots of ultra-high capacity density, along with a need to be energy efficient. The purpose of the project will be to show how resource and topology management can be better controlled by applying learning strategies, such as machine learning, both on a local and system wide basis. The project will establish where the learning/reasoning should best reside (nodes and/or network), and also the degree of control information exchange required between nodes. A mixture of simulation and analysis will be used to assess performance. Game theory and Markov analysis are likely to be important analytical tools. Key objectives To investigate how cognitive radio techniques can be applied to Software Defined Network (SDN) in 5G networks. To explore how backhaul diversity can be achieved in the network.

Project Title	Compact microwave multi-band band pass filters for 4/5G
Lead Organisation	University of York
Partners	N/A
Funding Source	N/A
Funding	N/A
Start / End	09/2014 - N/A
5G Classification Terms	Antenna, Baseband/Signal processing
Weblink	https://www.york.ac.uk/electronic-engineering/research/communication-technologies/projects/compact-uwave-filters/
Description (containing objectives, potential outcomes)	We have designed dual-band bandpass filters using different methods and resonators, including using TE01δ mode quarter cylindrical dielectric resonators [1], coaxial stepped impedance resonators [2], and non-uniform pitch helical resonators [3]. These multi-band bandpass filters are compact compared to using several single-band bandpass filters. They have relatively large power handling capability so that they are applicable for transceivers of LTE/5G micro/pico-cell base stations.

Project Title	Cognitive Radio for 5G Small cell systems employing smart antennas
Lead Organisation	University of York
Partners	N/A

Funding Source	N/A
Funding	N/A
Start / End	05/2013 - N/A
5G Classification Terms	MAC/RRM
Weblink	https://www.york.ac.uk/electronic-engineering/research/communication-technologies/projects/cognitive-radio-5g-small-cell/
Description (containing objectives, potential outcomes)	This project will examine how smart antennas can be used for future 5G small cell systems which share pooled spectrum. Spectrum assignment strategies will be developed which take into account time and spatially varying traffic profiles common in small cell systems, through changes in the beam pattern of both transmit and receive antennas. The impact of the degree of control information exchange required, possibly implemented through software defined networking, for systems possibly owned by multiple operators will be addressed. The benefits and drawbacks of such an approach compared with more conventional strategies will be evaluated. A mixture of simulation and analysis will be used to assess performance. Game theory and Markov analysis will be particularly important analytical tools.

Project Title	MiWaveS: Beyond 2020 Heterogeneous Wireless Networks with Millimetre-Wave Small Cell Access and Backhauling
Lead Organisation	COMMISSARIAT A L ENERGIE ATOMIQUE ET AUX ENERGIES ALTERNATIVES *
Partners	OPTIPRINT AG * NATIONAL INSTRUMENTS DRESDEN GMBH * TECHNISCHE UNIVERSITAET DRESDEN * INTEL DEUTSCHLAND GMBH * TECNOLOGIAS SERVICIOS TELEMATICOS Y SISTEMAS S.A. * Teknologian tutkimuskeskus VTT Oy * NOKIA SOLUTIONS AND NETWORKS OY * TEKNOLOGIAN TUTKIMUSKESKUS VTT * ORANGE SA * STMICROELECTRONICS S.A. * UNIVERSITE DE RENNES I * STMICROELECTRONICS SRL * TELECOM ITALIA SPA * SIVERS IMA AKTIEBOLAG * UNIVERSITY OF SURREY CENTRE NATIONAL DE LA RECHERCHE SCIENTIFIQUE CNRS * STMICROELECTRONICS CROLLES 2 SAS *
Funding Source	FP7

Funding	€ 7,358,113
Start / End	01/01/2014 - 30/04/2017
5G Classification Terms	Qos/QoE, Antenna, mmWAVE, HetNets, Radio Front-end/RF
Weblink	http://www.miwaves.eu
Description (containing objectives, potential outcomes)	Providing broadband wireless communications to a majority of European citizens is a major objective of the EC at the horizon of 2020. With a current annual growth rate in the range of 70%, the mobile data traffic of smartphones, tablets, machine-to-machine and other portable devices dramatically challenges the 4G wireless cellular network currently under deployment. To sustain this growth, high data-rate millimetre-wave (mmW) technologies, that demonstrate striking capabilities for short- and medium-range wireless communications, can bring a tremendous performance improvement. MiWaveS will develop the key technologies for the implementation of mmW wireless access and backhaul in future 5th Generation heterogeneous cellular mobile networks, taking advantage of the wide unlicensed or light-licensed frequency bands available to allow flexible spectrum usage as well as peak capacities above 10 Gbit/s aggregated throughput, well beyond the LTE-Advanced system. Installed in dense urban environments, miniature mmW small-cell access-points connected to the cellular network through optical fibre or mmW wireless backhaul will support massive data exchanges for mobile users with low latency, low interferences, high QoS and low power consumption per bit. They will also contribute to a reduced exposure of the public to electromagnetic fields (EMF) thanks to lower transmitted power and reduced skin penetration at mmW, steerable directive antennas focusing the signals in the directions of interest, and reduced data traffic through the lower frequency legacy base-stations. To lead this research in Europe, the MiWaveS consortium groups major network operators, equipment/component providers, OEMs, research institutes and academic institutions with world-known expertise in the relevant areas for designing and demonstrating heterogeneous cellular networks with mmW access and backhaul.

Project Title	5G AURA: Application-aware user-centric programmable architecture for 5G multi-tenant networks
Lead Organisation	CENTRE NATIONAL DE LA RECHERCHE SCIENTIFIQUE CNRS *
Partners	UNIVERSITAT POLITECNICA DE CATALUNYA * UNIVERSITY OF YORK TECHNISCHE UNIVERSITAET KAISERSLAUTERN * NEC EUROPE LTD EDUCATIONAL OTE AE * IQUADRAT INFORMATICA SL *

	FASMETRICS YPIRESIES KAI PROIONTA ILEKTROMAGNITIKON PEDION ANONYMI ETAIREIA *
Funding Source	H2020
Funding	€ 3,545,458.56
Start / End	01/10/2015 - 30/09/2019
5G Classification Terms	SDN, NFV, MEC (Mobile Edge Computing), Cloud RAN, mmWAVE
Weblink	http://www.h2020-msca-etn-5gaura.eu/home
Description (containing objectives, potential outcomes)	The vision of future 5G networks encompasses a heterogeneous communication landscape in which existing Radio Access Technologies (RATs) will be integrated with evolving wireless technologies and systems, software-design network architectures and cloud-enabled services. Effectively harnessing the potential of all these innovative and heterogeneous features and providing a programmable multi-tenant network architectural framework will be the key to the success of 5G, and will be the main objective of the 5G-AURA project. Instead of focusing separately on the optimization of the diverse technological and architectural components, our efforts will be concentrated on providing a unifying framework that will sustain the coexistence and coordination of networking, software and cloud technologies, ensure network programmability and efficient resource orchestration, minimize control and signalling overhead, support multi-tenancy and scalability, and promote the development of new business models for emerging services. To efficiently achieve these objectives, 5G-AURA has identified 12 specific research challenges which have been mapped to 14 individual projects that will be carried out by 14 recruited ESRs. The project's consortium, formed by four academic institutions and four industrial partners, has the necessary expertise and available infrastructures to form a high quality training network across multiple disciplines, sectors and countries. Considering that 5G is currently in an early development state and there are multiple open issues on 5G protocols, network architectures and technologies and standardization efforts, the timing of 5G-AURA is perfect, and the project has a strong potential to have significant impact on academia and industry and enhance the European innovation capacity in terms of technical contributions, intersectoral training of scientists and professional and novel business opportunities.

Project Title	Slicenet: End-to-end cognitive network slicing and slice management framework in virtualised multi-domain, multi-tenant 5G networks
Lead Organisation	EURESCOM-EUROPEAN INSTITUTE FOR RESEARCH AND STRATEGIC STUDIES IN TELECOMMUNICATIONS GMBH *
Partners	ALTICE LABS SA *

	UNIVERSITY OF THE WEST OF SCOTLAND NEXTWORKS * ERICSSON TELECOMUNICAZIONI * IBM ISRAEL - SCIENCE AND TECHNOLOGY LTD * EURECOM * UNIVERSITAT POLITECNICA DE CATALUNYA * REDZINC SERVICES LIMITED * HELLENIC TELECOMMUNICATIONS ORGANISATION S.A. - OTE AE (ORGANISMOS TILEPIKOINONION TIS ELLADOS OTE AE) * ORANGE ROMANIA SA * EFACEC ENERGIA - MAQUINAS E EQUIPAMENTOS ELECTRICOS SA * EMC INFORMATION SYSTEMS INTERNATIONAL * CREATIVE SYSTEMS ENGINEERING (C.S.E) MONOPROSOPI EPE * CIT INFINITE DESIGNATED ACTIVITY COMPANY *
Funding Source	H2020 (5G-PPP)
Funding	€ 7,979,030
Start / End	01/06/2017 - 31/05/2020
5G Classification Terms	Qos/QoE, NFV, SDN, Network Slicing, IoT - Smart Cities, IoT - Health, IoT - Industry 4.0, EPC
Weblink	https://slicenet.eu/
Description (containing objectives, potential outcomes)	5G use cases are so diverse and challenging that the 5G networks must be customisable for the broad range of individual scenarios. 5G network providers are keen to offer “networks as a service” where logical network slices are created and allocated to use cases flexibly and efficiently in a multi-operator environment. SliceNet will create and demonstrate the tools and mechanisms to achieve this ambition. Specifically, SliceNet will design, prototype and demonstrate an innovative, verticals-oriented, QoE-driven 5G network slicing framework. It will use cognitive network management, control and orchestration techniques for the provision and operation of end-to-end slicing across multi-operator domains in 5G networks. SliceNet will systematically tackle a range of the involved outstanding issues and thus directly addresses the key challenges in Strand 3 “Software Network” in this call ICT-07-2017. The integrated SliceNet framework will be demonstrated in three representative vertical use cases: Smart Grid, eHealth and Smart City, to highlight the achievements, innovations, and impacts. SliceNet support the unique perspectives and requirements on 5G networks of different players: For 5G verticals businesses, SliceNet offers an innovative one-stop shop solution to meet diverging and demanding service requirements. SliceNet enables the verticals to plug and play their use cases with bespoke control to employ 5G slices in a scalable, cost-efficient way via novel mySlice and Scalable Slicing as a Service functions and a one-stop API. For 5G service providers and users, SliceNet provides

	unprecedented guaranteed service quality by agile cognitive QoE-optimisation of service creation and delivery. For 5G network operators, SliceNet presents an integrated FCAPS (Fault, Configuration, Accounting, Performance, Security) framework for truly end-to-end management, control and orchestration of slices by secured, interoperable, and reliable operations across multi-operator domains.

Project Title	Selfnet: A framework for self-organised network management in virtualised and software defined networks
Lead Organisation	EURESCOM-EUROPEAN INSTITUTE FOR RESEARCH AND STRATEGIC STUDIES IN TELECOMMUNICATIONS GMBH *
Partners	UNIVERSIDAD DE MURCIA * ALTICE LABS SA * DEUTSCHES FORSCHUNGSZENTRUM FUR KUNSTLICHE INTELLIGENZ GMBH * UNIVERSITY OF THE WEST OF SCOTLAND UNIVERSIDAD COMPLUTENSE DE MADRID * NEXTWORKS * INNOROUTE GMBH * ALVARION TECHNOLOGIES LTD * UBIWHERE LDA * PROEF, SGPS SA * CREATIVE SYSTEMS ENGINEERING (C.S.E) MONOPROSOPI EPE *
Funding Source	H2020 (5G-PPP)
Funding	€ 6,866,496
Start / End	01/07/2015 - 30/06/2018
5G Classification Terms	Qos/QoE, SDN, NFV, Network Slicing, Network Automation, System Integration / Validation / Simulation
Weblink	https://selfnet-5g.eu/
Description (containing objectives, potential outcomes)	The proposed SELFNET project will design and implement an autonomic network management framework to achieve self-organizing capabilities in managing network infrastructures by automatically detecting and mitigating a range of common network problems that are currently still being manually addressed by network operators, thereby significantly reducing operational costs and improving user experience. SELFNET explores a smart integration of state-of-the-art technologies in Software-Defined Networks (SDN), Network Function Virtualization (NFV), Self-Organizing Networks (SON), Cloud computing, Artificial intelligence, Quality of Experience (QoE) and Next-generation networking to provide a novel intelligent network management framework that is capable of assisting network

	operators in key management tasks: automated network monitoring by the automatic deployment of NFV applications to facilitate system-wide awareness of Health of Network metrics to have more direct and precise knowledge about the real status of the network; autonomic network maintenance by defining high-level tactical measures and enabling autonomic corrective and preventive actions against existing or potential network problems. SELFNET is driven by use cases designed to address major network management problems including Self-protection capabilities against distributed cyber-attacks, Self-healing capabilities against network failures, and Self-optimization to dynamically improve the performance of the network and the QoE of the users. SELFNET is designed within this economic and business context to substantially reduce operational costs of network operators by automating a significant number of current labour-intensive network management tasks. Therefore, SELFNET directly addresses the Strand Network Management challenge highlighted by the EC.

Project Title	SAT5G: Satellite and terrestrial networks for 5G
Lead Organisation	AVANTI COMMUNICATIONS LTD
Partners	THALES ALENIA SPACE FRANCE * UNIVERSITY OF SURREY SES TECHCOM SA * AIRBUS DEFENCE AND SPACE SAS * ONEACCESS SA * NEDERLANDSE ORGANISATIE VOOR TOEGEPAST NATUURWETENSCHAPPELIJK ONDERZOEK TNO * BRITISH TELECOMMUNICATIONS PUBLIC LIMITED COMPANY TriaGnoSys GmbH * BROADPEAK * GILAT SATELLITE NETWORKS LTD * VT IDIRECT SOLUTIONS LTD * INTERUNIVERSITAIR MICRO-ELECTRONICA CENTRUM * FUNDACIO PRIVADA I2CAT, INTERNET I INNOVACIO DIGITAL A CATALUNYA * OULUN YLIOPISTO * QUORTUS LTD
Funding Source	H2020 (5G-PPP)
Funding	€ 8,316,502.50
Start / End	01/06/2017 - 30/11/2019
5G Classification Terms	NFV, SDN, MEC (Mobile Edge Computing), Satellite , System Integration / Validation / Simulation
Weblink	http://sat5g-project.eu/

Description (containing objectives, potential outcomes)	The introduction and global roll out of eMBB service within 5G raises coverage and network dimensioning issues in underserved and unserved areas, especially in low ARPU regions of emerging markets, and on mobile platforms (e.g. vessels and aircraft). Satcom systems are the only economic solution to address these scenarios provided that they are seamlessly integrated into the future 5G architecture and optimum efficiency is achieved via technological synergies between 5G mobile and satcom systems. SaT5G will bring satcom into 5G by defining optimal satellite-based backhaul and traffic offloading solutions. It will research, develop and validate key 5G technologies in order to take the best value of satcom capabilities (e.g. multicast for content and VNF delivery, ubiquity and resiliency) and mitigate its inherent constraints (e.g. latency). It will identify novel business models and economically viable operational collaborations that integrate the satellite and terrestrial stakeholders in a win-win situation. SaT5G will validate, through specific research pillars, the required technology bricks that will enable the targeted markets to be addressed. The project gathers key stakeholders from the global satcom industry partnering with MNOs, SMEs and research centres with the expertise from cellular network operation, architecture design, transmission, virtualisation, network management, business modelling, security, content multicast & caching. The SaT5G External Advisory Board involves MNOs, satellite and vertical stakeholders. SaT5G will capitalise on and drive the standardisation effort initiated in 3GPP and ETSI since Q3 2015 by several consortium partners and Advisory Board members. A key feature of SaT5G is demonstrations of satellite integration in 5G network testbeds to validate the technology developed and scenarios. The project aims to be the main vector for defining the integration of satellite solutions for 5G in 3GPP.

Project Title	5GXCast: Broadcast and multicast communication enablers for the fifth generation of wireless systems
Lead Organisation	UNIVERSITAT POLITECNICA DE VALENCIA *
Partners	NOKIA SOLUTIONS AND NETWORKS OY * NOKIA SOLUTIONS AND NETWORKS MANAGEMENT INTERNATIONAL GMBH * BRITISH BROADCASTING CORPORATION BRITISH TELECOMMUNICATIONS PUBLIC LIMITED COMPANY BROADPEAK * BUNDLESLAB KORLATOLT FELELOSSEGU TARSASAG * EXPWAY * FAIRSPECTRUM OY * INSTITUT FUR RUNDFUNKTECHNIK GMBH * LiveU Ltd. *

	NOMOR RESEARCH GMBH * ONE2MANY BV * SAMSUNG ELECTRONICS (UK) LIMITED TELECOM ITALIA SPA * TURUN AMMATTIKORKEAKOULU OY * UNION EUROPEENNE DE RADIO TELEVISION-EBU * UNIVERSITY OF SURREY
Funding Source	H2020 (5G-PPP)
Funding	€ 7,999,920
Start / End	01/06/2017 - 31/05/2019
5G Classification Terms	MAC / RRM, Media (AR/VR), Automotive, Business Models, Baseband/ Signal processing, EPC, System Integration / Validation / Simulation
Weblink	http://5g-xcast.eu/
Description (containing objectives, potential outcomes)	5G-Xcast will devise, assess and demonstrate large scale immersive media delivery by means of conceptually novel wireless technologies, contributing to the further definition of 5G and its standardisation. 5G-Xcast will focus on large scale media distribution, as this use case is one of the most demanding requirements in terms of data rate (capacity), scalability (cost-effectiveness) and ubiquity (coverage). The 5G-Xcast media delivery solution will have built-in unicast/multicast/broadcast modes and caching capabilities. The project will take a holistic approach in order to harmonize media delivery across the three communication modes being considered, and to provide a seamless user experience, as well as common Application Programming Interfaces (APIs) to content service providers. The project will cover multiple disciplines from the radio interface to the transport and application layers, including protocols and APIs, as well as network and system architecture aspects. The development of the 5G-Xcast media delivery solution will be focused on the Media and Entertainment (M&E) vertical. The automotive, Internet of Things and public safety verticals will be considered to ensure that their respective technical requirements are also identified and suitably addressed. Proof-of-concept prototypes and technology demonstrators are pivotal tasks of the project. Special emphasis will be given to emerging new immersive media services that cannot be efficiently delivered by existing technologies and networks. 5G-Xcast will enable progressive convergence in the media delivery sector while optimising the resources of the available infrastructures, enabling new business models over fixed, mobile and broadcast networks that will be also investigated in the project. The consortium is a balanced combination of telecom and media entities, covering the complete M&E value chain, with a very strong presence in 5G-PPP phase-1 and 3GPP standardization of 4G

	Broadcast.

Project Title	To-EURO-5G: Supporting the European 5G Initiative
Lead Organisation	EURESCOM-EUROPEAN INSTITUTE FOR RESEARCH AND STRATEGIC STUDIES IN TELECOMMUNICATIONS GMBH *
Partners	THE 5G INFRASTRUCTURE ASSOCIATION * INSTITUT DE L'AUDIOVISUEL ET DES TELECOMMUNICATIONS EN EUROPE - IDATE * INTERINNOV SAS * NOKIA SOLUTIONS AND NETWORKS MANAGEMENT INTERNATIONAL GMBH * UNIVERSITY OF SURREY ALMA MATER STUDIORUM - UNIVERSITA DI BOLOGNA * ORANGE SA * MARTEL GMBH * TELENOR ASA * NOKIA BELL LABS FRANCE * WATERFORD INSTITUTE OF TECHNOLOGY *
Funding Source	H2020 (5G-PPP)
Funding	€ 2,522,708.75
Start / End	01/06/2017 - 31/08/2019
5G Classification Terms	Other
Weblink	https://5g-ppp.eu/to-euro-5g/
Description (containing objectives, potential outcomes)	The To-Euro-5G project has a clear objective to support the activities of the European 5G Initiative as outlined in the 5G contractual Public Private Partnership (cPPP) during the second phase of the 5G-PPP from June 2017 to June 2019, with the intention of maximising the return on this investment for Europe. . The objectives of To-Euro-5G include: • Progressing the 5G-PPP high level goal of maintaining and enhancing the competitiveness of the European ICT industry, and seeking European leadership in the 5G domain. • Supporting activities where the 5G-PPP can contribute to the implementation of the European 5G Action Plan. • Assembling an overview of the 5G-PPP projects trial/demo/showcase potential and encouraging any organisation performing such an activity to identify the “European 5G” basis of their public showcases. • Responsibility for orchestrating the cross project activities of the 5G-PPP projects selected for Phase 2 of the 5G-PPP, as foreseen by Article 41.4 of their respective grant agreements, for

	example, in the areas of Standards, Spectrum, Architecture, management, Security and a number of other key strategic aspects of 5G. • Developing and implementing a strategic communications plan, including technical and social media channels, to ensure the best possible impact is achieved with the results of the 5G-PPP projects and the horizontal activities of the 5G-PPP programme. • Stimulating, organising and hosting strategic events and workshops where the European 5G achievements will be promoted on a global level. • Orchestrating an open, transparent and flexible 5G-PPP programme governance structure that facilitates good co-operation between the projects, the commission and the 5G Infrastructure Association. . The To-Euro-5G project also has the underlying ambition to ensure that European society, via the Vertical sectors uptake of 5G, can enjoy the economic and societal benefits these future 5G networks can provide.

Project Title	SoftFire: Software defined networks and network function virtualization testbed within FIRE+
Lead Organisation	EIT DIGITAL *
Partners	DEUTSCHE TELEKOM AG * ERICSSON TELECOMUNICAZIONI * FRAUNHOFER GESELLSCHAFT ZUR FOERDERUNG DER ANGEWANDTEN FORSCHUNG E.V. * SECURITY REPLY SRL * TECHNISCHE UNIVERSITAET BERLIN * TELECOM ITALIA SPA * UNIVERSITY OF SURREY ADS ASSEMBLY DATA SYSTEM SPA *
Funding Source	H2020
Funding	€ 4,384,510
Start / End	01/02/2016 - 30/04/2018
5G Classification Terms	NFV, SDN, EPC, Network Automation, Network Slicing, Security
Weblink	https://www.softfire.eu/
Description (containing objectives, potential outcomes)	SoftFIRE+ partners are aiming at Research and Innovation actions pursuing the integration of existing experimental facilities, testbeds and laboratories into FIRE+. The project focuses on new technologies like SDN and NFV in order to create a reliable, secure, interoperable and programmable experimental network infrastructure within the FIRE+ initiative. The Consortium will federate existing

	experimental testbeds in order to create an infrastructure that Third Parties can use to develop new services and applications. The federation is a step towards the creation of a new network experimental infrastructure that could be used as an initial 5G oriented platform. The SoftFIRE+ testbed will offer the possibility to assess and improve programmable solutions. In this environment there are three key elements to consider: programmability, interoperability and security. These properties have to be assessed in terms of efficiency, functional responsiveness and in general terms E2E QoS. The main objective of this project is to demonstrate and assess the level of maturity of adopted solutions and to show how they can support the full potential of these properties in a real world infrastructure by creating, nurturing and supporting an ecosystem of Third parties able to make use of the SoftFIRE+ testbed and to functionally extend it. The project aims at creating a broad ecosystem of companies engaged with the evolution of the SoftFIRE+ testbed. In order to achieve this goal, the project will spend a considerable part of its effort and budget for involving Third parties in the usage and consolidation of the platform. The mechanisms envisaged for this are: Open Calls and specific events (like Hackathon, Plug-tests and Challenges). The federated infrastructure will be used in order to a) develop new services and applications from Third parties, and b) develop new platform functionalities.

Project Title	iJOIN: Interworking and joint design of an open access and backhaul network architecture for small cells based on cloud networks
Lead Organisation	FUNDACION IMDEA NETWORKS *
Partners	TECHNISCHE UNIVERSITAET DRESDEN * UNIVERSITAET BREMEN * TELEFONICA INVESTIGACION Y DESARROLLO SA * UNIVERSIDAD CARLOS III DE MADRID * INTEL MOBILE COMMUNICATIONS FRANCE * SAGEMCOM BROADBAND SAS * COMMISSARIAT A L ENERGIE ATOMIQUE ET AUX ENERGIES ALTERNATIVES * HEWLETT PACKARD ITALIANA SRL * TELECOM ITALIA SPA * NEC EUROPE LTD UNIVERSITY OF SURREY
Funding Source	FP7
Funding	€ 3,689,000
Start / End	01/11/2012 - 30/04/2015

5G Classification Terms	Cloud RAN, Energy Efficiency, MAC / RRM, HetNets
Weblink	https://cordis.europa.eu/project/rcn/105819_en.html
Description (containing objectives, potential outcomes)	Motivation. The last decades brought an exponential increase in mobile traffic volume. This will continue and a 1000-fold increase by 2020 has been forecasted. Small-cells promise to provide the required data rates through an increased spatial utilisation of the spectrum. Problem statement. Due to strong inter-cell interference, small-cell deployments will require a high degree of coordination as offered by centralised processing. Furthermore, heterogeneous backhaul solutions will be used to connect small-cells and core network. So far, access and backhaul are individually designed and therefore not optimised. In order to support centralised processing and a heterogeneous backhaul, challenges on access and backhaul must be simultaneously tackled. Approach. iJOIN introduces the novel concept RAN-as-a-Service (RANaaS), where RAN functionality is flexibly centralised through an open IT platform based on a cloud infrastructure. iJOIN aims for a joint design and optimisation of access and backhaul, operation and management algorithms, and architectural elements, integrating small-cells, heterogeneous backhaul, and centralised processing. Additionally to the development of technology candidates across PHY, MAC, and the network layer, iJOIN will study the requirements, constraints, and implications for existing mobile networks, specifically 3GPP LTE-A. Results. iJOIN will design new network operation and management algorithms in the context of RANaaS, show their implications on 3GPP LTE, and evaluate the derived technologies with respect to four quantitative key objectives: 1) system throughput2) energy-efficiency3) cost-efficiency4) utilisation-efficiency iJOIN will further impact 1) the research community by identifying new challenges, 2) business opportunities through new concepts for implementing mobile networks, and3) standardisation through strong industry participation of all major stakeholders.

Project Title	Speed 5G: Quality of service provision and capacity expansion through extended DSA for 5G
Lead Organisation	University of Surrey
Partners	EURESCOM-EUROPEAN INSTITUTE FOR RESEARCH AND STRATEGIC STUDIES IN TELECOMMUNICATIONS GMBH * BRITISH TELECOMMUNICATIONS PUBLIC LIMITED COMPANY COMMISSARIAT A L ENERGIE ATOMIQUE ET AUX ENERGIES ALTERNATIVES * INTEL DEUTSCHLAND GMBH * INTRACOM SA TELECOM SOLUTIONS *

	INSTITUTO DE TELECOMUNICACOES * ROHDE & SCHWARZ GMBH&CO KOMMANDITGESELLSCHAFT * SISTELBANDA SA * WINGS ICT SOLUTIONS INFORMATION & COMMUNICATION TECHNOLOGIES EPE *
Funding Source	H2020 (5G-PPP)
Funding	€ 5,612,382
Start / End	01/07/2015 - 31/03/2018
5G Classification Terms	MAC / RRM, HetNets
Weblink	https://speed-5g.eu/
Description (containing objectives, potential outcomes)	The objective of SPEED-5G is to research and develop technologies that address the well-known challenges of predicted growth in mobile connections and traffic volume. A major challenge is the cost of meeting the objective, in terms of both infrastructure and deployment. Today, lack of dynamic control across wireless network resources is leading to unbalanced spectrum loads and a perceived capacity bottleneck. These will be solved by SPEED-5G through eDSA (extended DSA), which is resource management with three degrees of freedom: densification, rationalized traffic allocation over heterogeneous wireless technologies, and better load balancing across available spectrum. SPEED-5G will investigate indoor and indoor/outdoor scenarios where capacity demands are the highest, but also where the eDSA will be the most effective at exploiting co-operation across technologies and bands. The project will focus on two major innovations which are currently missing: resource management techniques across technology ‘silos’, and medium access technologies to address densification in mostly unplanned environments. It will leverage flexible radio approaches expected in 5G (e.g. FBMC). SPEED-5G has a very strong consortium, with a mix of operators, industrial partners, SMEs and leading European research institutes. They bring considerable knowledge and technology background to the project in architecture, resource management, protocols, radios, standardization, trials and tests, along with the most advanced of trial facilities, like the 5GIC centre. The SPEED-5G innovations will be considered in an architectural framework consistent with the 5GPPP. They will be researched, implemented and trialled in SPEED-5G in order to reach high level of maturity and confidence. This will guarantee impact on the 5GPPP program as a whole, on standards and on European technical leadership.

Project Title	Euro-5G
Lead Organisation	EURESCOM-EUROPEAN INSTITUTE FOR RESEARCH AND STRATEGIC STUDIES IN TELECOMMUNICATIONS GMBH *
Partners	THE 5G INFRASTRUCTURE ASSOCIATION * INSTITUT DE L'AUDIOVISUEL ET DES TELECOMMUNICATIONS EN EUROPE - IDATE * INTERINNOV SAS * NOKIA SOLUTIONS AND NETWORKS MANAGEMENT INTERNATIONAL GMBH * NOKIA SOLUTIONS AND NETWORKS GMBH &CO KG * UNIVERSITY OF SURREY ALMA MATER STUDIORUM - UNIVERSITA DI BOLOGNA * ORANGE SA * MARTEL GMBH * TELENOR ASA *
Funding Source	H2020 (5G-PPP)
Funding	€ 1,826,143
Start / End	01/07/2015 - 30/09/2017
5G Classification Terms	Other
Weblink	https://5g-ppp.eu/euro-5g/
Description (containing objectives, potential outcomes)	The primary objective of the Euro-5g project is to facilitate effective and efficient co-operation and integration between all projects of the 5G-PPP, the European Commission, The 5G-Infrastructure Association, Networld2020 ETP, related projects from EUREKA, and related national initiatives to maximize the European momentum towards, and benefits from, the future 5G integrated, ubiquitous and ultra-high capacity networks. The metrics for evaluating the success of 5G PPP will be based on the KPIs included in the 5G-PPP Contractual Arrangement signed by the 5G Infrastructure Association on behalf of the European ICT Sector and the European Commission in December 2013. This project is closely linked with the 5G-Infrastructure Association and will strive to ensure there is a seamless integration of the European industrial policies, as generated by the association, with the work plans of the projects under this program so the results will be the as useful and relevant as is possible. In its work, the Euro-5g project will actively support the 5G-PPP goal to maintain and enhance the competitiveness of the European ICT industry and to ensure that European society can enjoy the economic and societal benefits these future networks will bring in collaboration with the European commission, the 5G Infrastructure Association, the Networld2020 European Technology Platform and the projects of the

	5G-PPP

Project Title	AI to 5G SON
Lead Organisation	University of Surrey
Partners	BT
Funding Source	EPSRC
Funding	N/A
Start / End	09/2016 -09/2019
5G Classification Terms	MAC / RRM
Weblink	http://gtr.rcuk.ac.uk/projects?ref=studentship-1817330
Description (containing objectives, potential outcomes)	PhD Studentship - The goal of this is to explore the range of data available in a 5G network, and to exploit this data using self-learning / AI techniques to perform network self-organisation (SON). This organisation could be looking at a combination of spectrum allocation, power, allocation of users to (multiple simultaneous) cells, resource allocation, power, allocation of resources, location of virtualised network functions et.

Project Title	Stepping towards the industrial 6th sense
Lead Organisation	University of Surrey
Partners	Pertofac IBM UK Petroleum Industry Asc ZTE Fluor Honeywell
Funding Source	EPSRC
Funding	£ 1,016,391
Start / End	01/11/2017 - 31/10/2020
5G Classification Terms	IoT - Industry 4.0
Weblink	http://gow.epsrc.ac.uk/NGBOViewGrant.aspx?GrantRef=EP/R001588/1

Description (containing objectives, potential outcomes)	We, human beings, acquire information from our surroundings through our sensory receptors of vision, sound, smell, touch and taste -the five senses. The sensory stimulus is converted to electrical signals as nerve impulse data communicated with our brain. What is really intriguing is the communication network. When one or more senses fail (impairment), we are able to re-establish communication and improve our other senses to protect us from incoming dangers. Furthermore, we have developed the mechanism of "reasoning", effectively analysing the present data and generating a vision of the future, which we might call our 6th Sense (6S). Is it possible to develop a 6S technology to predict a catastrophic disaster? Industrial processes are already equipped with five senses: "hearing" from acoustic sensors, "smelling" from gas and liquid sensors, "seeing" from camera, "touching" from vibration sensors and "tasting" from composition monitors. 6S could be achieved by forming a sensing network which is self-adaptive and self-repairing, carrying out deep-thinking analysis with even limited data, and predicting the sequence of events via integrated system modelling. This project is the first step towards developing a 6S technology for industrial processes by bringing together research expertise in process systems engineering, wireless communication network, robotic and autonomous systems. The 6S technology developed in this project could be further explored to a wide range of industrial and manufacturing processes.

Project Title	TASCC/CARMA: Cloud Assisted Real-time Methods for Autonomy
Lead Organisation	University of Warwick
Partners	University of Surrey Transport Research Laboratory Thales Telefonica (O_2) Nokia (HERE)
Funding Source	EPSRC
Funding	£ 2,601,075
Start / End	15/06/2016 -15/06/2021
5G Classification Terms	MEC (Mobile Edge Computing), MAC / RRM, Security, Automotive
Weblink	http://gow.epsrc.ac.uk/NGBOViewGrant.aspx?GrantRef=EP/N01300X/1 http://gow.epsrc.ac.uk/NGBOViewGrant.aspx?GrantRef=EP/N01300X/2
Description (containing objectives,	Automotive industry and the consumers are eager for smart features on new cars and more efficient vehicles. Modern cars are not considered as mere means for travelling from point A to B anymore, but rather smart

potential outcomes)	systems that offer personalised services and have the capability to adapt to the user's preferences and needs. They are expected to become intelligent agents that learn from their environments and exploit various sources of information to become increasingly autonomous systems that relieve the driver from tedious tasks, such as parking, and improve safety, efficiency, and desirability of the future cars. From a wider angle, today's land transportation systems claim about 1.3 million lives and 7 million injuries in road accidents, according to a recent report by CISCO. The increasing number of cars results in traffic jams costing about 90 billion of lost hours for the drivers and the passengers. In addition, transportation accounts for about 26% of the total greenhouse gas emission from human activities. While public transport can help, cars remain to be the desired means of transport according to a recent report by the Department of Transport in 2014. These market forces in addition to the environmental, economic and social impacts of transport systems demand a timely and transformative research to rethink the automotive control systems and revolutionise vehicle design for future cars. There have been two trends towards this objective in the past decade: in the one hand the research in autonomous systems, inspired by unmanned space vehicles, gave birth to driver-less concept cars such as Google robotic car; on the other hand, modern wireless communications enabled cars to talk to each other and the roadside infrastructures, resulting in the concept of connected cars. However, driver-less cars remain to be too expensive for commercial vehicles (Google's cars cost about £100,000 only for sensing equipment) and connected vehicles can offer little if not properly integrated into smart and autonomous features. This ambitious research is defined by a number of world-class academic institutions and leading industrial partners to work with Jaguar Land Rover, a market leader in high end cars, to design and validate a framework that combines the power of connected vehicles concept with the notion of autonomous systems and build a novel platform for cost-effective deployment of autonomous features and ultimately realisation of connected and fully autonomous cars. This can be made possible thanks to modern wireless technologies and the power of cloud computing that allows sharing expensive computing resources (hence, reducing costs per vehicle) and provides access to information that are only available on the cloud. To realise the ambition of the project, a number of key challenges in the areas of ultra-low-latency wireless technologies, cloud computing, distributed control systems, and human interaction issues will be addressed in this project. In addition, potential security threats will be identified and analysed to assess the potential risks for the public and reputational damage for car manufacturers should such technologies be commercialised. At the end of the project, the technical solutions will be integrated into a single framework and will be validated by example applications, characterising technical and service-level performance of the

	framework, and providing a basis for the future direction of enhanced automated services. While the objective here is to ultimately enable affordable driver-less cars, in the short term, this project aims to enable a number of demonstrable autonomous features in a test environment.

Project Title	Academic Centre of excellence in cyber security research
Lead Organisation	University of Surrey
Partners	N/A
Funding Source	EPSRC
Funding	£ 20,185
Start / End	01/07/2015 - 30/06/2017
5G Classification Terms	Security
Weblink	http://gow.epsrc.ac.uk/NGBOViewGrant.aspx?GrantRef=EP/N002717/1
Description (containing objectives, potential outcomes)	The University of Surrey has established the Surrey Centre for Cyber Security to consolidate, organise and promote our Cyber Security activities across the University. The Centre builds on the existing capability and resources across the University of Surrey, which has been investing in Cyber Security research as a high-priority research area since 2004. The Centre focuses on three main research directions - Privacy and Data Protection, Secure Communications, and Human-Centred Security - building on the University's strength and the background of members of the Centre. Recognition of the Centre as an Academic Centre of Excellence in Cyber Security Research will help in consolidating research activities that are currently carried out across three faculties, and in creating new synergies for long-term collaborative research projects on the emerging interdisciplinary challenges of Cyber Security. It will also foster the international visibility and positioning of the Centre and expand its linkage with businesses, industry research institutions, and governmental bodies. The initial composition of the Centre consists of 8 Core Members from Computing and Electronic Engineering (Institute for Communication Systems), with established track records in selected key areas of Cyber Security. Within the University there are also a further 19 Associate Members, who hold strong research expertise in areas that are strategically important in addressing interdisciplinary cyber security challenges and where existing mutual interests and potentials are likely to

	lead to the establishment of joint research initiatives within the proposed Centre. In the short-term the Surrey Centre for Security will: - consolidate and promote its research activities, - establish an efficient organisation and management structure (including an Advisory Board), - identify new directions and bid for interdisciplinary and technology-focused cyber-security research projects, - establish a regular seminar series, - expand on its postgraduate teaching and PhD programmes, - refine its strategy upon the consultations with its liaison officer from GCHQ (and other governmental stakeholders). In the medium-term the Centre will - actively bid for new research projects and increase its research output in high-quality publication venues, - engage in collaborative projects with other ACE-CSRs and our partners.

Project Title	DARE: Distributed autonomous and resilient emergency management system
Lead Organisation	University of Surrey
Partners	University of Glasgow, Kingston University Ubitech BT Telefonica (O_2) Huawei Uni of Malaya (Malaysia) *
Funding Source	EPSRC
Funding	£ 1,193,567
Start / End	01/05/2017 - 30/04/2020
5G Classification Terms	Network Automation, HetNets, Other
Weblink	http://gow.epsrc.ac.uk/NGBOViewGrant.aspx?GrantRef=EP/P028764/1
Description (containing objectives, potential outcomes)	Critical infrastructures serve as the pillars for the nation's economy, security and health programmes and include assets, systems, and networks spanning a significant breadth of the its geographical area. In the event of a potential destruction to these infrastructures by either man-made or natural disasters, it is of paramount importance to implement an appropriate emergency management system (EMS) capable of handling or

	preventing such catastrophes. A key feature in an EMS is an effective and efficient critical communication platform that provides situational awareness and coordination. However, the current communication platforms for EMS are susceptible to being incapacitated or destroyed by the disaster or the network congestion that arise as a result of such disaster. Furthermore, current platforms are human-in-the-loop based, requiring substantial human resources and cost for surveillance, preparation and actuation in case of emergencies. In the light of this, the aim of the project is to conduct advanced research into a new Distributed Autonomous and Resilient EMS; referred here as DARE. The DARE architecture will support all phases of the EMS and will be founded upon three main communication platforms that are Wireless Sensor networks (WSNs), Ad-hoc networks and Future cellular networks (5G and beyond). As part of this research project, we will incorporate an autonomous i.e. self-governed, self-healing disaster/network failure detection mechanism to reduce the cost of control signalling traffic associated with the traditional disaster/network failure detection mechanisms which require frequent network probes and network alarms. Investigators from the University of Surrey, University of Glasgow, Kingston University and the University of Malaya, Malaysia will work with leading communications and critical solutions provider like Ubitech Ltd, BT, Telefonica and Huawei to ensure that maximum impact arises from this program.

Project Title	IoT LAB - Researching crowdsourcing to extend IoT testbed infrastructure for multidisciplinary experiments, with more end-user interactions, flexibility, scalability, cost efficiency and societal added value
Lead Organisation	MANDAT INTERNATIONAL ALIAS FONDATION POUR LA COOPERATION INTERNATIONALE *
Partners	UNIVERSITE DE GENEVE * ALEXANDRA INSTITUTTET A/S * INSTITOUTO TECHNOLOGIAS YPOLOGISTONKAI EKDOSEON DIOFANTOS * DRUSTVO ZA KONSALTING, RAZVOJ I IMPLEMENTACIJU INFORMACIONIH I KOMUNIKACIONIH TEHNOLOGIJA DUNAVNET DOO * LULEA TEKNISKA UNIVERSITET * UNIVERSITY OF SOUTHAMPTON UNIVERSITY OF SURREY
Funding Source	FP7

Funding	€ 2,565,000
Start / End	01/10/2013-10-01 - 30/09/2016
5G Classification Terms	IoT - Smart Cities, Other
Weblink	http://www.iotlab.eu/
Description (containing objectives, potential outcomes)	IoT Lab is a research project exploring the potential of crowdsourcing to extend IoT testbed infrastructure for multidisciplinary experiments with more end-user interactions. It will research and develop: 1. Crowdsourcing mechanisms and tools enabling testbeds to use third parties resources (such as mobile phones), and to interact with distributed users (the crowd). The crowdsourcing enablers will address issues such as privacy by design, identity management, security, reputation mechanisms, and data ownership.2. Virtualization of crowdsourcing and testbed components by using a meta-layer with an open interface, facilitating the integration and interaction with heterogeneous components. It should ease data integration and reduce the cost of deployment in real environment.3. Ubiquitous Interconnection and Cloudification of the testbeds resources. It will research the potential of IPv6 and network virtualization to interconnect heterogeneous and distributed resources through a Virtual IoT Network and will integrate them into the Cloud to provide an on-line platform of crowdsourcing Testbed as a Service (TBaaS) available to the research community.4. End-user and societal value creation by analysing the potential end-users and crowdsourcing participants to propose an optimized model for end-user adoption and societal value creation.5. "Crowdsourcing-driven research" as a new model in which the research can be initiated, guided and assessed by the crowd. It will compare it to other models.6. Economic dimension of crowdsourcing testbed, by analysing the potential markets and business models able to monetize the provided resources with adequate incentives, in order to optimize the exploitation, costs, profitability and economic sustainability of such testbeds. It will also develop tools for future experiments.7. Performing multidisciplinary experiments, including end-user driven experiments through crowdsourcing, to assess the added value of such approach.

Project Title	EXPERIMEDIA: Experiments in live social and networked media experiments
Lead Organisation	UNIVERSITY OF SOUTHAMPTON
Partners	EVOLARIS NEXT LEVEL GMBH * BEARINGPOINT INFONOVA GMBH * JOANNEUM RESEARCH FORSCHUNGSGESELLSCHAFT MBH * SCHLADMING 2030 GMBH *

	STI INTERNATIONAL CONSULTING UND RESEARCH GMBH * TECHNISCHE UNIVERSITAET GRAZ * KATHOLIEKE UNIVERSITEIT LEUVEN * FUNDACION TECNALIA RESEARCH & INNOVATION * STT INGENIERIA Y SISTEMAS SL * CENTRE D'ALT RENDIMENT ESPORTIU DE SANT CUGAT DEL VALLES * ATOS SPAIN SA * UNIVERSIDAD DE VIGO * REALTRACK SYSTEMS SL * LA F@BRIQUE DU FUTUR ASSOCIATION * INSTITUTE OF COMMUNICATION AND COMPUTER SYSTEMS * IDRIMA MEIZONOS ELLINISMOU * ETHNIKO KENTRO EREVNAS KAI TECHNOLOGIKIS ANAPTYXIS * UNIVERSITY OF PELOPONNESE * CENTRE DE RECHERCHE PUBLIC HENRI TUDOR * NEDERLANDSE ORGANISATIE VOOR TOEGEPAST NATUURWETENSCHAPPELIJK ONDERZOEK TNO * INSTYTUT CHEMII BIOORGANICZNEJ POLSKIEJ AKADEMII NAUK * QUALISYS AB * RISE INTERACTIVE INSTITUTE AB * IN2 SEARCH INTERFACES DEVELOPMENT LIMITED
Funding Source	FP7
Funding	€ 6,887,663
Start / End	01/11/2011 - 30/09/2014
5G Classification Terms	Qos/QoE, System Integration / Validation / Simulation
Weblink	http://www.experimedia.eu/
Description (containing objectives, potential outcomes)	Offering collective and participative experiences to real-world and online communities is at the heart of the Future Media Internet (FMI) and will form an essential part of entertainment, education, collaborative working, product and service innovation and advertising. Communities involved potentially include hundreds of professionals, tens of thousands at live public events and millions online. Current FIRE testbeds fail to meet needs of FMI researchers in terms of testbed resources, let alone support such experimentation in the real-world where insights into the behaviour of Future Internet systems are closer to reality. Extensive research into testbeds is needed to support the R&D of large-scale social and networked media systems as well as to understand and manage complex communities and ecosystems.EXPERIMEDIA will develop and operate a unique facility that offers researchers what they need for large-scale FMI experiments. Testbed technologies will include user-generated high

	quality content management and delivery, a 3D Internet platform and tools for 3D reconstruction from live events, augmented reality platform, tools for integration of social networks, access technologies and a range of network connectivity options. Testbed management services will provision, control and monitor resources according to SLAs thus offering QoS guarantees. Experiments will be conducted in the real-world at live events and to diverse communities to accelerate the adoption of FMI. Testbeds include the Schladming Ski Resort, the Multi-Sport High Performance Centre of Catalonia, historical sites provided by the Foundation for the Hellenic World and the 3D Innovation Living Lab. Experiments will explore new forms of social interaction and rich media experiences considering the demands of online and real-world communities. The variety of testbeds will ensure the generality of our approach. A Future Media Internet Competence Centre will promote sustainable access to venues for FMI experiments and engagement with the wider community.

Project Title	FIEAST-IoT: Federated interoperable semantic IoT testbeds and applications
Lead Organisation	NATIONAL UNIVERSITY OF IRELAND GALWAY *
Partners	UNIVERSITY OF SOUTHAMPTON INSTITUT NATIONAL DE RECHERCHE ENINFORMATIQUE ET AUTOMATIQUE * UNIVERSITY OF SURREY UNPARALLEL INNOVATION LDA * EASY GLOBAL MARKET SAS * NEC EUROPE LTDU UNIVERSIDAD DE CANTABRIA * ASSOCIATION PLATE-FORME TELECOM * RESEARCH AND EDUCATION LABORATORY IN INFORMATION TECHNOLOGIES * SOCIEDAD PARA EL DESARROLLO REGIONAL DE CANTABRIA SA * AYUNTAMIENTO DE SANTANDER * KOREA ELECTRONICS TECHNOLOGY INSTITUTE * FRAUNHOFER GESELLSCHAFT ZUR FOERDERUNG DER ANGEWANDTEN FORSCHUNG E.V. *
Funding Source	H2020
Funding	€ 5 135 287
Start / End	01/02/2015 - 31/01/2018
5G Classification Terms	IoT - Smart Cities
Weblink	https://cordis.europa.eu/project/rcn/194117_en.html

Description (containing objectives, potential outcomes)	Despite the proliferation of IoT and smart cities testbeds, there is still no easy way to conduct large scale experiments that leverage data and resources from multiple geographically and administratively distributed IoT platforms. Recent advances in IoT semantic interoperability provide a sound basis for implementing novel cloud-based infrastructures that could allow testbed-agnostic access to IoT data and resources. FIESTA will open new horizons in IoT experimentation at a global scale, based on the interconnection and interoperability of diverse IoT testbeds. FIESTA will produce a first-of-a-kind blueprint experimental infrastructure (tools, techniques and best practices) enabling testbed operators to interconnect their facilities in an interoperable way, while at the same time facilitating researchers in deploying integrated experiments, which seamlessly transcend the boundaries of multiple IoT platforms. FIESTA will be validated and evaluated based on the interconnection of four testbeds (in Spain, UK, France and Korea), as well as based on the execution of novel experiments in the areas of mobile crowd-sensing, IoT applications portability, and dynamic intelligent discovery of IoT resources. In order to achieve global outreach and maximum impact, FIESTA will integrate an additional testbed and experiments from Korea, while it will also collaborate with IoT experts from USA. The participation of a Korean partner (based its own funding) will maximize FIESTA's value for EC money. Moreover, the project will take advantage of open calls processes towards attracting third-parties that will engage in the integration of their platforms within FIESTA or in the conduction of added-value experiments. As part of its sustainability strategy, FIESTA will establish a global market confidence programme for IoT interoperability, which will enable innovative platform providers and solution integrators to ensure/certify the openness and interoperability of their developments.

Project Title	FED4FIRE: Federation for FIRE+
Lead Organisation	INTERUNIVERSITAIR MICRO-ELECTRONICA CENTRUM *
Partners	NATIONAL ICT AUSTRALIA LIMITED * IMINDS * BE-MOBILE * TELEVIC RAIL NV * GIBSON INNOVATIONS BELGIUM * EURESCOM-EUROPEAN INSTITUTE FOR RESEARCH AND STRATEGIC STUDIES IN TELECOMMUNICATIONS GMBH * TECHNISCHE UNIVERSITAET BERLIN * FRAUNHOFER GESELLSCHAFT ZUR FOERDERUNG DER ANGEWANDTEN FORSCHUNG E.V. * UNIVERSIDAD DE CANTABRIA * ADELE ROBOTS SOCIEDAD LIMITADA * TELEVES SA * FUNDACIO PRIVADA I2CAT, INTERNET I INNOVACIO DIGITAL A

	CATALUNYA * UNIVERSITAT POLITECNICA DE CATALUNYA * DEIMOS SPACE SOCIEDAD LIMITADA UNIPERSONAL * ATOS SPAIN SA * UNIVERSIDAD AUTONOMA DE MADRID * TELTEK VIDEO RESEARCH SL * UNIVERSIDAD DE MALAGA * UNIVERSIDAD CARLOS III DE MADRID * INSTITUT NATIONAL DE RECHERCHE ENINFORMATIQUE ET AUTOMATIQUE * UNIVERSITE PIERRE ET MARIE CURIE - PARIS 6 * NATIONAL TECHNICAL UNIVERSITY OF ATHENS - NTUA * PANEPISTIMIO THESSALIAS * MAGYAR TUDOMANYOS AKADEMIA SZAMITASTECHNIKAI ES AUTOMATIZALASI KUTATOINTEZET * THE PROVOST, FELLOWS, FOUNDATION SCHOLARS & THE OTHER MEMBERS OF BOARD OF THE COLLEGE OF THE HOLY & UNDIVIDED TRINITY OF QUEEN ELIZABETH NEAR DUBLIN * NATIONAL UNIVERSITY OF IRELAND GALWAY * CONSORZIO NAZIONALE INTERUNIVERSITARIO PER LE TELECOMUNICAZIONI * CREATE-NET (CENTER FOR RESEARCH AND TELECOMMUNICATION EXPERIMENTATION FOR NETWORKED COMMUNITIES) * Liberologico Srl * SCUOLA SUPERIORE DI STUDI UNIVERSITARI E DI PERFEZIONAMENTO SANT'ANNA * NATIONAL INFORMATION SOCIETY AGENCY * INSTYTUT CHEMII BIOORGANICZNEJ POLSKIEJ AKADEMII NAU * PRIVREDNO DRUSTVO ZA PRUZANJE USLUGA ISTRAZIVANJE I RAZVOJ NISSATECH INNOVATION CENTRE DOO * INSTITUT JOZEF STEFAN * GEANT LIMITED LANCASTER UNIVERSITY UNIVERSITY OF BRISTOL BRITISH TELECOMMUNICATIONS PUBLIC LIMITED COMPANY THE UNIVERSITY OF EDINBURGH UNIVERSITY OF SOUTHAMPTON UNIVERSITY OF KENT CENTRE NATIONAL DE LA RECHERCHE SCIENTIFIQUE CNRS * EDUCATIONAL FOUNDATION YONSEI UNIVERSITY *
Funding Source	FP7
Funding	€ 7,749,997
Start / End	01/10/2012 - 31/12/2016
5G Classification Terms	SDN, NFV, Optical Network, Network Slicing, Other

Weblink	https://www.fed4fire.eu/
Description (containing objectives, potential outcomes)	A federation of experimentation facilities will significantly accelerate Future Internet research. Fed4FIRE will deliver open and easily accessible facilities to the FIRE experimentation communities, which focus on fixed and wireless infrastructures, services and applications, and combinations thereof. The project will develop a demand-driven common federation framework, based on an open architecture and specification. It will be widely adopted by facilities and promoted internationally. This framework will provide simple, efficient, and cost effective experimental processes built around experimenters' and facility owners' requirements. Insight into technical and socio-economic metrics, and how the introduction of new technologies into Future Internet facilities influences them, will be provided by harmonized and comprehensive measurement techniques. Tools and services supporting dynamic federated identities, access control, and SLA management will increase the trustworthiness of the federation and its facilities. A FIRE portal will offer brokering, user access management and measurements. Professional technical staff will offer first-line and second-line support to make the federation simple to use. The project will use open calls to support innovative experiments from academia and industry and to adapt additional experimentation facilities for compliance with Fed4FIRE specifications. A federation authority will be established to approve facilities and to promote desirable operational policies that simplify federation. A Federation Standardization Task Force will prepare for sustainable standardization beyond the end of the project. The adoption of the Fed4FIRE common federation framework by the FIRE facilities, the widespread usage by both academic and industrial experimenters, and the strong links with other national and international initiatives such as the FI-PPP, will pave the way to sustainability towards Horizon 2020.

Project Title	New air interface techniques for future massive machine-type communications
Lead Organisation	University of Surrey
Partners	University of Southampton AccelerComm GE (General Electric Company) Huawei Group NEC Sony Europe Limited (UK) Thales Ltd
Funding	EPSRC

Source	
Funding	£ 855,121
Start / End	01/12/2017 - 30/11/2020
5G Classification Terms	MAC / RRM, System Integration / Validation / Simulation
Weblink	http://gow.epsrc.ac.uk/NGBOViewGrant.aspx?GrantRef=EP/P03456X/1 http://gow.epsrc.ac.uk/NGBOViewGrant.aspx?GrantRef=EP/P034284/1
Description (containing objectives, potential outcomes)	In this project, we propose to meet the challenges of future mMTC by investigating and designing novel non-orthogonal multiple access, flexible duplexing, and adaptive coherent-no coherent transmission schemes, as well as new waveforms that are tailored for the future mMTC systems. We aim for alleviating the strict synchronism demanded by the legacy wireless systems, and for significantly improving their capabilities, network performance as well as the lifetime of autonomous mMTC nodes. The novelties of this project are summarized as follows. 1. New non-orthogonal sparse code multiple access (SCMA) schemes will be developed for mMTC systems, where the number of devices exceeds the number of available resource-slots, resulting in an over-loaded or a generalized rank-deficient condition. 2. Novel multicarrier waveforms will be designed for future mMTC in order to maximize spectrum efficiency by minimizing the overhead for achieving synchronisation as well as for reducing the out-of-band radiation. 3. By jointly exploiting the resources available in the time, frequency and spatial domains, we will design noncoherent, partially-coherent and adaptive coherent-noncoherent transmission schemes, in order to strike the best possible trade-off among overhead reduction, energy and spectral efficiency, latency and implementation complexity in practical mMTC scenarios. 4. We will investigate the full potential of the multicarrier-division duplex (MDD) scheme and, especially, its applications to future mMTC by synergistically combining it with novel multicarrier waveforms, non-orthogonal SCMA techniques and other high-efficiency transmission schemes developed within the project. 5. Furthermore, the key techniques developed in the project will be prototyped and integrated into the 5G Innovation Centre (5GIC) test bed facilities at the University of Surrey. This will allow us to demonstrate the viability of our new design approaches, as well as to accelerate knowledge transfer and commercialisation. The proposed research will be conducted jointly by the 5GIC at the University of Surrey and Southampton Wireless (SW) at the University of

	Southampton, led by Xiao, Tafazolli, Yang & Hanzo. The research and commercial exploitation of the project will be further consolidated by our partnership with experienced academic and industrial partners.

Project Title	5G ENSURE: 5G Enablers for Network and System Security and Resilience
Lead Organisation	Teknologian tutkimuskeskus VTT Oy *
Partners	THALES SERVICES SAS * NOKIA BELL LABS FRANCE * B-COM * ERICSSON AB * UNIVERSITY OF SOUTHAMPTON OY L M ERICSSON AB * NEC EUROPE LTD NIXU OYJ * ORANGE SA * RISE SICS AB * THALES ALENIA SPACE ESPANA, SA * THALES COMMUNICATIONS & SECURITY SAS * TELECOM ITALIA INFORMATION TECHNOLOGY SRL * TELECOM ITALIA SPA * TRUST-IT SERVICES LIMITEDU THE CHANCELLOR, MASTERS AND SCHOLARS OF THE UNIVERSITY OF OXFORD
Funding Source	H2020 (5G-PPP)
Funding	€ 7,584,046.25
Start / End	01/11/2015 - 31/10/2017
5G Classification Terms	EPC, NFV, SDN, Network Slicing, Security
Weblink	http://www.5gensure.eu/
Description (containing objectives, potential outcomes)	5G-ENSURE will define and deliver a 5G Security Architecture, shared and agreed by the various 5G stakeholders. It will specify, develop and release an initial set of useful and usable security enablers for 5G. These enablers will be selected for their relevance in addressing some of the foremost security concerns in order to generate the trust and confidence necessary for 5G to be widely adopted and to deliver its promises through innovative business applications. The 5G-ENSURE project will also initiate a 5G Security testbed vision and initial set-up in which the security enablers will be made available. Moreover, the potential of the developed 5G Security enablers will be showcased and demonstrated in the context of carefully selected 5G security use cases (e.g. use cases related to cybersecurity and aerospace).

	Coupled with this, 5G-ENSURE will be closely linked to the overall 5G PPP programme through active participation in common activities and fora. Specifically, 5G-ENSURE will be the project that creates and animates a dedicated 5G PPP Security Working Group to coordinate the various security-related activities. 5G-ENSURE is led by a strong consortium bringing together the appropriate and complementary skills, including standards involvement and deep telco understanding, along with an extensive network of interested parties, and have a proven track-record in coordination. 5G-ENSURE will avail itself of the support of a group of international opinion leaders.

Project Title	Software Defined Cognitive Networking: Intelligent Resource Provisioning For Future Networks
Lead Organisation	University of Northampton
Partners	Hewlett-Packard Company Inc, US * Lancaster University
Funding Source	EPSRC
Funding	£ 99,771
Start / End	11/2017 - 10/2019
5G Classification Terms	SDN, Qos/QoE, Media (AR/VR)
Weblink	http://gtr.rcuk.ac.uk/projects?ref=EP%2FP033202%2F1
Description (containing objectives, potential outcomes)	The non-cooperative competition of network resources between a growing number of adaptive media applications has a significant detrimental impact on user experience and network efficiency. This can lead to knock-on effects to the digital economy and digital public services, which are increasingly dependent on high quality and reliable media streaming. Existing network infrastructures often prioritise improved network coverage and fast packet forwarding functions, which do not always effectively contribute to the improved user experience. Ultimately, the quality of user experience and network efficiency are the two of the most important benchmarks for online media distribution. Future network management must leverage application and user-level cognitive factors in order to allocate scarce network resources effectively and intelligently. this First Grant project aims at developing software defined cognitive networking (SDCN) to ensure the user experience, user-level fairness and network efficiency of online adaptive media using

	SDN-assisted and QoE-aware resource management. SDCN will lay the groundwork for a great leap from the conventional resource provisioning and traffic engineering schemes to context-aware network management. In order to achieve its objective, the project will develop a cognitive model based on the analysis of human factors of adaptive media experience, iterations of subjective experiments, and data modelling. The model will enable a non-intrusive QoE assessment service that monitors adaptive media flows and estimates their perceptual user experience using a number of application, service, and network-level metrics. The model will use a purpose-built multi-objective resource allocation function to derive optimal solutions to provision available network resource for the improved user experience, fairness and network efficiency in a network segment.

Project Title	Liquid Antennas
Lead Organisation	University of Liverpool
Partners	BAE Systems City University of Hong Kong * Huawei Technologies Co Limited (Global) *
Funding Source	EPSRC
Funding	£ 587,312
Start / End	01/06/2017 - 31/05/2020
5G Classification Terms	Antenna, Radio Front-end / RF
Weblink	http://gow.epsrc.ac.uk/NGBOViewGrant.aspx?GrantRef=EP/P015751/1
Description (containing objectives, potential outcomes)	In this project, we are going to develop a new type of antenna: liquid antennas, which will offer all the advantages but overcome the problems that water antennas have. The main challenges are 1) How to identify the most suitable liquid materials with low loss, thermal and mechanical stability which will work over the desired temperature range (from -30 to +60 degree C), frequency range (from kHz to GHz), and RF/microwave power range (up to kW). 2) How to design and make compact and efficient liquid antennas which are flexible or reconfigurable in terms of the main antenna parameters (such as the operational frequency, radiation pattern, and size) and suitable for real world applications.

	This is an interdisciplinary project which requires expertise from radio frequency (RF) and microwave engineering, chemical and material science. It consists of both theoretical and experimental work. A wide range of liquid materials (not limited to water and sea water) will be studied, especially ionic liquids and antifreezes. Their electromagnetic, thermal and mechanical properties will be screened against temperature, frequency and RF/microwave power levels with the ultimate goal being to make reconfigurable, small liquid antennas to work efficiently and effectively over a wide temperature, frequency and power range. In addition, the reconfigurable techniques suitable for liquid antennas will also be studied thoroughly and two reconfigurable liquid antennas will be developed, optimised to demonstrate their excellent potential features for both military and commercial applications. The work will be undertaken in collaboration with industrial leaders (BAE Systems and Huawei) and academic expert (Prof Luk from Hong Kong) to ensure that this research will bring new knowledge into material science and radio engineering, a novel type of antenna will be introduced to meet the demands from the industry and provide an alternative compact reconfigurable and/or flexible device to the wireless world. The research outcomes of this study (e.g. the liquid and reconfigurable technology) could be extended to other RF and microwave devices (such as filters, delay lines and phase shifters) where low-loss dielectric materials may be used.

Project Title	Advanced signal processing techniques for MU-MIMO broadband wireless communications
Lead Organisation	Queen's University Belfast
Partners	N/A
Funding Source	EPSRC
Funding	£ 210,325
Start / End	05/01/2007 - 04/07/ 2010
5G Classification Terms	Massive / MU-MIMO, Baseband/ Signal processing
Weblink	http://gow.epsrc.ac.uk/NGBOViewGrant.aspx?GrantRef=EP/D07827X/1
Description (containing objectives, potential outcomes)	The field of wireless communications technology is currently undergoing tremendous expansion, which has been brought about by the rapid proliferation of many diverse and exceptionally compelling commercial, governmental, and consumer applications including wireless internet and multimedia communications. As the wireless industry becomes ubiquitous

	and popular, arguably the most critical condition of current wireless communications systems is the need for a much larger capacity to support multiusers simultaneously. Supporting such requirements using wireless techniques poses significant technical challenges due to the nature of multipath fading wireless channels and co-channel interferences. In this context, multiple-input multiple-output (MIMO) technology has been identified as a key technology because of effectiveness in improving the capacity and range of wireless communications both in mobile cellular and ad hoc local area networks. As a result of the need for quality of service and capacity, as well as the demonstrated benefits of the MIMO architectures, developing multiuser MIMO systems becomes the key driver in this proposed research interest. The overall aim of the research proposed herein is to develop efficient signal processing strategies for next generation cooperative multiuser MIMO broadband cellular and ad hoc networks. The new systems and algorithms developed in this project will enable the future wireless networks to push simultaneously serviceable users as near to the capacity limits as possible. For wireless users, this aim translates into shorter service response times, fewer waits and faster connections

Project Title	WISDOM: Wideband Low-Cost Smart Passive and Active Integrated Antennas for THz Wireless Communications
Lead Organisation	University of Kent
Partners	University of Warwick
Funding Source	EPSRC
Funding	£ 291,064
Start / End	01/01/2017 - 31/12/2019
5G Classification Terms	Antenna
Weblink	http://gow.epsrc.ac.uk/NGBOViewGrant.aspx?GrantRef=EP/P015840/1 http://gow.epsrc.ac.uk/NGBOViewGrant.aspx?GrantRef=EP/P015905/1
Description (containing objectives, potential outcomes)	Wideband low-cost Smart passive and active integrated antennas for THz wireless communications (WISDOM) proposes a significant advance towards the design and fabrication of smart, wideband and low-cost THz devices. In order to do so, the consortium is built from very complementary expertise with knowledge on 3D printing, antenna, THz circuit and system. A first key element of WISDOM, is the use of 3D inkjet printing for fast fabrication of THz passive and active antennas. This approach will be combined with THz circuit designs in CMOS. Using multi-material 3D inkjet printing of functional materials to simultaneously deposit conductive and

	dielectric materials; including thermal and UV rapid solidification of deposited structures, efficient coupling between on-chip signals to free-space radiation will be achieved. This will lead to an important breakthrough that combines two cheap and high-volume technologies, paving a path to consumer-oriented THz products. A second key element is the combination of the 3D-on-CMOS printing technology with spatial-power combining array antennas, in order to develop highly-efficient THz beams that overcome the increased free-space path loss that prevents THz consumer products today. In WISDOM, we also plan to demonstrate the concepts with smart spatial power-combining active array architecture for wideband THz wireless communications. The core WISDOM ICs will be used as active pixels providing spatial power combining with full individual amplitude and phase settings of each pixel in transmit and receive mode. Due to the use of 3D printing (for antennas) and CMOS process (for circuits), it dramatically reduces the cost of THz devices and systems while providing significant advances in THz frontend adaptability. A number of wideband antenna elements, arrays, on-chip active antennas as well as THz front ends circuits (>300 GHz) will be designed, fabricated and measured.

Project Title	High performance wireless/photonic interfaces for 60 GHz radio over fibre applications
Lead Organisation	Compound Semiconductor Technologies Global Limited
Partners	University of Glasgow Optocap Limited
Funding Source	Innovate UK
Funding	£ 285,389
Start / End	01/2018 - 12/2018
5G Classification Terms	Optical Network, Radio Front-end / RF, Other
Weblink	http://gtr.rcuk.ac.uk/projects?ref=103443
Description (containing objectives, potential outcomes)	In this project, the semiconductor device technology required to achieve multi-gigabit wireless transmission and reception is integrated with the capabilities of semiconductor optical device and fibre networks in order to improve the speed, security, and cost required for point to point communication links. The scheme exploits the recent development of standards and techniques around those frequencies in the millimetre wave spectrum, specifically in the V-band of frequencies. The high data rate possible with this wireless-opto technology (>7Gbps) is several times larger than the data rates currently used in

	the wireless communications industry. The technology has also additional benefits in terms of immunity from interference, and reduced size of components and antennas. The wireless-opto interface devices in this project share the same platform of compound semiconductor (III-V) material (InP). For the wireless part of the interface, the active component is implemented in the form of a resonant tunnelling diode RTD (oscillator). For the optical part of the interface, the active component is implemented as a high speed distributed feedback (DFB) laser. Both integrated components form the single package wireless-opto transceiver solution.

Project Title	NIRVANA: Intelligent, heterogeneous virtualised networking infrastructure
Lead Organisation	University of Kent
Partners	University of Essex BT EE Limited JDSU UK Ltd NEC Qualcomm Cambridge Limited Techgate plc
Funding Source	EPSRC
Funding	£ 926,417
Start / End	01/10/2014 - 30/04/2018
5G Classification Terms	MEC (Mobile Edge Computing), D2D, HetNets, Energy Efficiency, Cloud RAN
Weblink	http://www.intelligent-nirvana.net/
Description (containing objectives, potential outcomes)	The Internet is expanding towards mobile wireless connectivity rapidly. However, to enable this for increasing numbers of users and connected devices, and increasingly bandwidth-, processing power- and energy-hungry applications, will require a transformation in the way in which current mobile and wireless networks perform. Shorter wireless distances (small cells, picocells, femtocells) and different network types for the connection (Wi-Fi, 3G, 4G, 5G) depending on the availability and suitability for different applications, is a process that is already happening and expected to continue. This will manifest itself with simpler remote radio heads providing coverage in otherwise difficult to penetrate locations (and the main processing functions gathered together in a centralised pool of base station baseband units), and with the appearance of new wireless standards. NIRVANA takes this evolution and proposes a transformative step: the incorporation of fast, hardware-based,

	network monitoring, and intelligence (using the monitoring/gathered information) close to the pool of base stations. The proximity of the intelligence enables low-overhead control of a range of operational functions, which allow users to be moved from one connection type to another, according to their application and the load on the network, and to match the network's resources precisely to user needs. It allows energy efficiency to be optimised throughout the network and in the mobile device, too. The latter is augmented by locating the computing resources for a "mobile cloud" near the base station pool. Some processing is offloaded to the mobile cloud instead of being done on the mobile, and even some mobile-to-mobile communication may be done within this cloud - saving the mobile device (and the network) energy that would have been used in radio transmissions. Finally, among the new wireless connection types to be investigated, millimetre-wave communications, using the most up-to-date releases of the wireless local area network standard (802.11ad/j), will be fashioned into a device-to-device mesh network, for mobile distributed caching, which will be shown to further enhance the capacity of the network and its energy efficiency.

Project Title	UFORIC: Ultra-Fast Optical Routing including Impairment Constraints
Lead Organisation	University of Essex
Partners	N/A
Funding Source	EPSRC
Funding	£ 210,378
Start / End	20/11/2006 19/11/2009
5G Classification Terms	Optical Network, Routing
Weblink	http://gow.epsrc.ac.uk/NGBOViewGrant.aspx?GrantRef=EP/D062500/1
Description (containing objectives, potential outcomes)	The research to be undertaken within UFORIC proposes an ultra-fast control plane concept that relies on using a hardware-based protocol to route information across an all-optical switched network. Since a signal traversing through an all-optical network acquires optical impairments along the transmission links and the switching nodes, the concept will develop a concept that allows a path to be chosen that minimises particular optical impairments and guarantees an acceptable level of degradation (= bit-error rate). Essentially, the UFORIC control plane will simultaneously find a path through the network that satisfies both the bandwidth and optical performance requirements of a requesting service. Since the majority of the processing is done at very high speed within a field programmable gate array (FPGA), this will be many orders of magnitude

	faster than can be achieved using today's software-based solutions. This is essential for optical packet- and burst-switched networking concepts of the future. The trade-off, however, will be the accuracy in the choice of paths and this will be determined within the scope of the project. The UFORIC control plane will be integrated into an all-optical research network testbed to demonstrate its operation.

Project Title	CHARISMA: Converged Heterogeneous Advanced 5G Cloud-RAN Architecture for Intelligent and Secure Media Access
Lead Organisation	FUNDACIO PRIVADA I2CAT, INTERNET I INNOVACIO DIGITAL A CATALUNYA *
Partners	FRAUNHOFER GESELLSCHAFT ZUR FOERDERUNG DER ANGEWANDTEN FORSCHUNG E.V.* NATIONAL CENTER FOR SCIENTIFIC RESEARCH "DEMOKRITOS" * APFUTURA INTERNACIONAL SOLUCIONES SL * INNOROUTE GMBH * INCITES CONSULTING SARL * JCP-CONNECT * UNIVERSITY OF ESSEX COSMOTE KINITES TILEPIKOINONIES AE * INTRACOM SA TELECOM SOLUTIONS * TELEKOM SLOVENIJE DD * ALTICE LABS SA * ETHERNITY NETWORKS LTD * ERICSSON ESPANA SA *
Funding Source	H2020 (5G-PPP)
Funding	€ 5,892,245
Start / End	01/07/2015 - 31/12/2017
5G Classification Terms	NFV, SDN, MEC (Mobile Edge Computing), Network Slicing, Optical Network, Cloud RAN, mmWAVE, D2D, Security
Weblink	http://www.charisma5g.eu/
Description (containing objectives, potential outcomes)	CHARISMA proposes an intelligent hierarchical routing and paravirtualised architecture that unites two important concepts: devolved offload with shortest path nearest to end-users and an end-to-end security service chain via virtualized open access physical layer security (PLS). The CHARISMA architecture meets the goals of low-latency (<1ms) and security required for future converged wireless/wireline advanced 5G networking. This provides a cloud infrastructure platform with increased spectral and energy efficiency and enhanced performance targeting the identified needs for 1000-

	fold increased mobile data volume, 10-100 times higher data rates, 10-100 times more connected devices and 5x reduced latency. Fully aligned and committed to the 5G-PPP principles and KPIs, the CHARISMA proposal brings together 10G-wireless (via mm-wave/60-GHz & free-space optics, FSO) access and 100G fixed optical (OFDM-PON) solutions through an intelligent cloud radio-access-network (C-RAN) and intelligent radio remote head (RRH) platform with IPv6 Trust Node routing featuring very low-latency for the traffic management. Low-cost Ethernet is used across front- and backhaul, and end-user equipment (vCPE), and intelligence distributed across the back-, front-hauls, and perimetric data transports. Ad-hoc mobile device interconnectivities (D2D, D2I, C2C etc.), content delivery network (CDN) and mobile distributed caching (MDC) offer an energy-efficient (better than x20 improvement possible) information-centric networking (ICN) architecture. Furthermore, caching will provide efficient utilization of scarce resources by early aggregating data or/and by executing communication locally. The CHARISMA approach will benefit user experiences with ground-breaking low-latency services, high-bandwidth, and mobile cloud resilient network security.

Project Title	FLEx: FIRE LTE testbeds for open experimentations
Lead Organisation	PANEPISTIMIO THESSALIAS *
Partners	NATIONAL ICT AUSTRALIA LIMITED * INTERUNIVERSITAIR MICRO-ELECTRONICA CENTRUM * IMINDS * TELEVIC RAIL NV * UNIVERSITAET BERN * TECHNISCHE UNIVERSITAET BERLIN Germany FRAUNHOFER GESELLSCHAFT ZUR FOERDERUNG DER ANGEWANDTEN FORSCHUNG E.V * UNIVERSIDAD DE MALAGA * FUNDACIO PRIVADA I2CAT, INTERNET I INNOVACIO DIGITAL A CATALUNYA * UNIVERSITE PIERRE ET MARIE CURIE - PARIS 6 * RED TECHNOLOGIES * EURECOM * ORION INNOVATIONS PRIVATE COMPANY * UNIVERSITY OF PIRAEUS RESEARCH CENTER * COSMOTE KINITES TILEPIKOINONIES AEGreece FERON TECHNOLOGIES IDIOTIKI KEFALAIOUCHIKI ETAIREIA * NATIONAL CENTER FOR SCIENTIFIC RESEARCH "DEMOKRITOS" * INTRACOM SA TELECOM SOLUTIONS * SOFTWARE RADIO SYSTEMS LIMITED *

	INTRASOFT INTERNATIONAL SA * CELERWAY COMMUNICATION AS * SIMULA RESEARCH LABORATORY AS * ALLBESMART LDA *l UBIWHERE LDA * UNIVERSITY OF NIS- FACULTY OF ELECTRONIC ENGINEERING * THE UNIVERSITY OF EDINBURGH Sirran Engineering Services Ltd IP.ACCESS LIMITED RUTGERS, THE STATE UNIVERSITY OF NEW JERSEY * CENTRE NATIONAL DE LA RECHERCHE SCIENTIFIQUE CNRS *
Funding Source	FP7
Funding	€ 3,799,295
Start / End	01/01/2014 - 30/04/2017
5G Classification Terms	SDN, NFV, D2D
Weblink	http://www.flex-project.eu/
Description (containing objectives, potential outcomes)	FIRE initiative targets the creation of a multidisciplinary research platform for investigation and experimental evaluation of innovative ideas in networking and services. At the infrastructure level, such a platform should embrace all major wired and wireless access technologies. FLEX aims at contributing a crucial missing piece in FIRE's infrastructure puzzle: cellular access technologies and Long-Term Evolution (LTE) in particular LTE 4G cellular networks are gradually being adopted by all major operators in the world and are expected to rule the cellular landscape at least for the current decade. They will also form the starting point for further progress, ushering in the era of 5G mobile networks. The lack of open or at least openly configurable cellular equipment and core network software has limited applied research in this field within the boundaries of vendor and operator R&D groups. In FLEX we will build programmable LTE components as extensions to existing European testbeds, thus providing an open and remotely accessible platform for experimentation with LTE. The deployment of LTE components will take place on three existing and well-established FIRE wireless testbeds, thus reducing the required integration effort, and placing it instead on novel aspects of LTE experimentation-driven research. FLEX's experimentation environment will feature both open source platforms and configurable commercial equipment that span macro-cell, pico-cell and small-cell setups. We will build upon current FIRE testbed management and experiment control tools and extend them to provide support for the new LTE components, and we will develop specialized monitoring tools and methodologies. Focus will be placed on mobility, with the

	establishment of both real and emulated mobility functionalities on the testbeds. FLEX will organize two open calls, aiming to attract research groups to conduct sophisticated experiments, test innovative usages or provide functional extensions of LTE testbeds

Project Title	CityFlow: OpenFlow City Experiment – Linking Infrastructure and Applications
Lead Organisation	THE UNIVERSITY OF EDINBURGH
Partners	IMINDS * REDZINC SERVICES LIMITED * ONE SOURCE CONSULTORIA INFORMATICA LDA *
Funding Source	FP7
Funding	€ 668,778
Start / End	01/10/2012 - 31/07/2014
5G Classification Terms	SDN, HetNets, Media (AR/VR)
Weblink	https://cordis.europa.eu/project/rcn/104971_en.html
Description (containing objectives, potential outcomes)	This Future Internet experiment will create a multi-autonomous-system experimental signalling overlay on the OFELIA OpenFlow infrastructure. We propose to marry an existing NSIS signalling stack, along with an existing multi autonomous system Virtual Path Slice controller, to the OFELIA OpenFlow experimental facility, thereby extending OpenFlow with signalling and multi-domain interworking on a multi-autonomous-system topology. We will use the Virtual Wall facility to emulate a city broadband network with up to 100 nodes, and will model the network based on best practices as observed in public internet production networks. The work will be conducted in three steps (i) experiment setup and configuration (ii) experiment implementation and (iii) showcase and demonstration. Altogether four experiments will be performed. The first experiment will verify the inter-working of NSIS and the VPS Controller with OpenFlow. The second experiment concerns signalling performance; the intention is to measure the performance of the control plane with high signalling load and identify what Busy Hour Connection Attempt (BHCA) performance can be achieved. The third experiment will measure the resilience of the virtual path slice in the context of high background traffic load for uni-directional and bi-directional traffic. Finally, another experiment will investigate how the system reacts under different failure scenarios.

	The showcase will demonstrate the benefit of signalling for two use cases: (a) a scenario for true HD video; and (b) a HD video-to-video scenario for real-time interactive traffic.

Project Title	DDAS: Digital Distributed Antenna System
Lead Organisation	University of Cambridge
Partners	Zinwave Ltd
Funding Source	EPSRC
Funding	£ 122,176
Start / End	01/09/2012 - 28/02/2014
5G Classification Terms	Antenna, Radio Front-end / RF
Weblink	http://gow.epsrc.ac.uk/NGBOViewGrant.aspx?GrantRef=EP/J013544/1
Description (containing objectives, potential outcomes)	This project will seek to commercialise research which has led to the development of a new paradigm in the distribution of wireless services. In short the targeted products will, for the first time, enable the distribution of multiple RF services over conventional internet infrastructure for the first time. It will allow full remote management and monitoring of such services, and enable a substantial increase in backhaul capacity. The concept behind this current proposal won the Cambridge University £5k Entrepreneur's Challenge in its field in 2011. To date in-building DAS systems have primarily been analogue and this results in limitations in the number of wireless channels, and hence the capacity, that can be transmitted over an individual optical fibre. If digital systems have been used, they have typically been configured for known, pre-determined, RF modulation formats and protocols, and require very high bandwidth digital links to transmit the signals. Up to now, this has been acceptable because conventional DAS systems have been used to ensure good coverage for mobile services with capacity requirements being relatively modest. However both analogue radio over fibre and conventional digital DAS have considerable limitations for likely future user needs where for the first time, capacity will become a very important issue, as it will affect the growth of high bandwidth services such as mobile video. This is because both conventional techniques essentially use large bandwidths which necessitate the use of individual back-haul fibres being required to address individual antennas. As such these systems become limited in their ability to scale to the numbers of antennas required to deliver on future bandwidth demands, and require the conversion from IP internet traffic to mobile communication

	standards to occur at a base station within the building from which the signals are carried on the DAS. For future systems therefore, where capacity will become as (and indeed more) important than coverage, a new technology is required. Recently we have devised a system concept able to solve this problem (even though it is able to use low bandwidth links such as twisted-pair cables), and in turn proposed how it would enable a new form of commercial model for the delivery of high bandwidth services in the future. The technology not only makes possible exploitation by hardware sales, but also offers the creation of new service models which a new companies could adopt, in effect creating the mobile service equivalent to 'cloud computing'. Thus this digital DAS (DDAS) project aims to develop a novel DAS which could take advantage of existing Ethernet infrastructure in such places to make them economically feasible to install. In addition, it offers a more flexible way of increasing capacity since the radio source is centralised. It intends to take the current laboratory demonstration of the low bit rate digital DAS system to commercialisation. The technical aspect of the work will focus on a prototype system to demonstrate to potential customers, investors or collaborators. The commercial development plan will develop relationships with customers and potential licensees while building a business plan with the aim of generating a spinout company at the end of the grant period.

Project Title	Elastic Optical Networks and Probabilistic Design
Lead Organisation	University of Cambridge
Partners	British Telecommunications
Funding Source	EPSRC
Funding	N/A
Start / End	10/2016 - 09/2020
5G Classification Terms	Optical Network
Weblink	http://gtr.rcuk.ac.uk/projects?ref=studentship-1775341
Description (containing objectives, potential outcomes)	The UK optical communication network requires constant improvement to route ever increasing demands at suitable QoS and latencies. Such an improvement could be found from increasing the efficiency of bandwidth allocation and from improved modelling of networks at a large scale. This project seeks to model and design an elastic optical network, wherein WDM channels can be grouped together, providing larger bandwidth for larger demands, or split into several separate channels to reduce overhead on smaller demands, thus increasing network

	efficiency. Given the scale of the UK communications grid, modelling this requires novel approaches to representing this type of system to shrink the computing requirements to reasonable levels. Statistical physics is purpose built for this task and by using concepts such as entropy and temperature to represent states of network activity we seek to reduce the computational complexity of the problem. This will allow modelling beyond the network backbone and could even show emergent 'group' properties of such systems. This representation will be paired with probabilistic design methods to provide either efficient ways to reinforce the current network or an entirely new network design which could replace the current network when economically viable. This will improve the performance and reliability of the UK communications infrastructure, ensuring its ability to cope with future increases in internet usage such as the 'Internet of Things' or high bitrate video streams.

Project Title	5G Millimetre-Wave Connectivity to Cars
Lead Organisation	Jaguar Land Rover
Partners	University of Bristol Blu Wireless British Telecommunications
Funding Source	Innovate UK
Funding	£ 195,873
Start / End	09/2017 - 08/2018
5G Classification Terms	mmWAVE, Automotive, System Integration / Validation / Simulation
Weblink	http://gtr.rcuk.ac.uk/projects?ref=132998
Description (containing objectives, potential outcomes)	This proposal considers testing, evaluating and enhancing the performance of 5G Vehicle to Infrastructure communications in a vehicular environment and in particular in a motorway-speed scenario. 5G mmWave communications will be explored for high data rate delivery and a feasibility study to evaluate the technology for mobility will be performed. Using Road Side Units (RSUs) spaced regularly along the motorway or road, data rates in the order of gigabits per second are anticipated. To overcome the high path loss at mmWave frequencies, adaptive beamforming will be used to focus signals to and from the vehicle. The project will perform real world radio channel measurements leading to data trials using a suitable demonstration system.

Project Title	Heterogeneous Mobile Edge Computing
Lead Organisation	University of Bristol
Partners	Toshiba
Funding Source	EPSRC
Funding	N/A
Start / End	10/2016 - 10/2020
5G Classification Terms	MEC (Mobile Edge Computing)
Weblink	http://gtr.rcuk.ac.uk/projects?ref=studentship-1834874
Description (containing objectives, potential outcomes)	This PhD project will investigate and propose innovative solutions for some of the following MEC-related topics: * Smart MEC computation scheduling and offloading; * Distributed data storage and caching * MEC platform management * Application-aware performance optimisation * Radio network-aware content optimisation * Real-time load prediction models * Reliable and scalable resource allocation * Context awareness

Project Title	Massive MIMO for 5G Communications
Lead Organisation	University of Bristol
Partners	Toshiba
Funding Source	EPSRC
Funding	N/A
Start / End	09/2015 - 09/2019
5G Classification Terms	Massive / MU-MIMO
Weblink	http://gtr.rcuk.ac.uk/projects?ref=studentship-1791039
Description (containing objectives, potential outcomes)	Fifth generation (5G) wireless communication has attracted tremendous research attention recently. As a key technology for 5G wireless communications, massive MIMO makes use of large-scale antenna arrays in either the transmitter, receiver, or both of them. The large antenna array gain will boost the received signal power drastically thus provide enhanced coverage. The channels obtained by the

	massive MIMO antenna array have very different characteristics from the conventional channel in many aspects. Algorithms selecting and driving these subarrays offer the potential advantage of balancing cost and performance for massive MIMO communication. This project will focus on first identifying the current state-of-the art theory, implementations and challenges. Novel architectures and algorithms will then be investigated to relax current requirements on the number of RF chains, size and number of subarrays

Project Title	SERAN: Seamless and adaptive wireless access for efficient future networks
Lead Organisation	University of Edinburgh
Partners	University of Sheffield University of Bristol Huawei Group NEC Roke Manor Research Ltd Thales Ltd Toshiba Mobile VCE Vodafone
Funding Source	EPSRC
Funding	£ 853,379
Start / End	01/01/2015 - 30/09/2018
5G Classification Terms	Qos/QoE, Baseband/ Signal processing, HetNets, MAC / RRM, Energy Efficiency
Weblink	http://gow.epsrc.ac.uk/NGBOViewGrant.aspx?GrantRef=EP/L026147/1
Description (containing objectives, potential outcomes)	Wireless communications is becoming a pervasive technology that we use throughout our lives. Across society, there is a move away from using the internet on desktop computers and towards mobile phones, laptops and tablets. This means that the amount of data transmission to support our online activity is rapidly increasing. There is also significant growth in automatic data sharing and collection from many types of sensors, meters and computers, sometimes called machine-to-machine communications. Mobile network operators face major challenges in setting up their networks to meet the increasing traffic load. They would like to provide a rich and seamless internet connection experience to their subscribers, but this must be traded off against the financial and energy costs of their network.

	There are three major concepts or trends that can assist mobile operators to improve their networks. The first is the concept of heterogeneous networks which includes both wide area large cells or macrocells and short range small cells that allows the network operator to target areas of high traffic demand such as offices or shopping malls. Using small cells provides a low cost and low energy solution to provide high data rate services to subscribers. The second concept is the use of more radio spectrum to meet traffic demand. The UK government has recently been auctioning more radio spectrum to network operators to boost capacity. However, by using a new set of higher frequency bands called the millimetre wave spectrum, much higher data rates may be achieved. The drawback is that radio signals do not propagate as far as for existing mobile broadband frequencies, so they are probably best suited to short range small cells. The third concept relates to efficient management of radio spectrum with a large number of small cells operating. The first danger in this scenario is that the complexity of managing the large number of cells and frequencies becomes impossibly complex. A second major problem relates to the potential for significant interference between small cells, which limits their efficiency. One solution to these problems are so-called "phantom cells". These use a separate higher power data link to coordinate the activities of all mobiles and thus limit the complexity of the system. This project will study new ideas to manage the growth of heterogeneous networks and the use of new spectrum bands in an efficient way. These methods will manage the network resources in a simple manner and will tackle interference effectively. They will yield a network that provides a good quality of experience to subscribers in a more energy efficient way than today's mobile networks.

Project Title	SONATAS: Synthetic on-chip and off-chip optical network systems
Lead Organisation	University of Bristol
Partners	Xilinx Corp, United States * Polatis Ltd
Funding Source	EPSRC
Funding	£ 98,215
Start / End	12/2014 - 06/2016
5G Classification	Optical Network

Terms	
Weblink	http://gtr.rcuk.ac.uk/projects?ref=EP%2FL027070%2F1
Description (containing objectives, potential outcomes)	The project will first investigate the formulation of function block behaviour realised both in electronics (i.e. data queuing, framing, protocols) and photonics (i.e. filtering, multiplexing, frequency/space switching). Such function blocks will be interconnected by a network topology (on-chip and off-chip) through the use of synthesis algorithms to compose a complete system. To deliver efficient synthesis, the composition framework and algorithms will consider infrastructure constraints (FPGA timing/space, and optical sub-system characteristics). Techniques will be devised and investigated to deliver isolation between distinct network programmable functions that co-exist on the same opto-electronic hardware substrate. The project provides direct contribution spanning across multiple EPSRC Priority Areas such as ICT networks and distributed systems as well as optical communications and micro-electronics design. Specifically it addresses the Towards an Intelligent Information Infrastructure (TI3) challenge. So it consequently fits with the EPSRC Working Together priority. It is this context that SONATAS is vital to the development of the future of information society.

Project Title	Spatially Embedded Networks
Lead Organisation	University of Oxford
Partners	University of Bristol BT Her Majesty's Government Communications InterDigital Mobile VCE NEC Thales Ltd Toshiba
Funding Source	EPSRC
Funding	£ 1,198,800
Start / End	06/10/2015 - 05/10/2018
5G Classification Terms	Propagation / Channel Modelling, Baseband/ Signal processing, Security
Weblink	http://www.eng.ox.ac.uk/sen/
Description (containing	In this project, the probabilistic formalism alluded to above will be exploited further to study several key concepts that influence the

objectives, potential outcomes)	structure of spatially embedded networks. The following four topics will be treated: - continuum models of spatially embedded networks, including the investigation of spectral and centrality properties of random networks; - mobility models in spatially embedded networks, including random waypoint and Levy flight processes; - trust models in spatially embedded networks, including trust dynamics and protocol design; - temporal models of spatially embedded networks, including dynamical node and link (edge) models. The work will take a mathematical approach, but will always maintain a focus on practical implications and designs.

Project Title	FLAME: Facility for large-scale adaptive media experimentation
Lead Organisation	UNIVERSITY OF SOUTHAMPTON
Partners	ATOS SPAIN SA * INTERDIGITAL EUROPE LTD FUNDACIO PRIVADA I2CAT, INTERNET I INNOVACIO DIGITAL A CATALUNYA * UNIVERSITY OF BRISTOL NEXTWORKS * MARTEL GMBH * DE VLAAMSE RADIO EN TELEVISIEOMROEPORGANISATIE NV * THE WALT DISNEY COMPANY (SWITZERLAND) GMBH * EIDGENOESSISCHE TECHNISCHE HOCHSCHULE ZUERICH * INSTITUT MUNICIPAL D'INFORMATICA DE BARCELONA *
Funding Source	H2020
Funding	€ 4,999,742
Start / End	01/01/2017 - 31/12/2019
5G Classification Terms	NFV, Media (AR/VR), Qos/QoE
Weblink	https://www.ict-flame.eu/
Description (containing objectives, potential outcomes)	The Future Media Internet (FMI) will be driven by evolving existing over-the-top (OTT) solutions towards a stronger integration with emerging programmable communication and computing infrastructures to address consumer demand for personalised, interactive, mobile and localised media experiences. Creating a trusted platform that brings together technology, creative sectors and consumers in the development of pioneering media applications and services will be crucial to drive European innovation and competitiveness. FLAME will address this goal by establishing an FMI ecosystem based on the Experimentation-as-a-Service (EaaS) paradigm that supports large-scale experimentation of novel FMI

	products and services using real-life adaptive experimental infrastructures encompassing not only the compute and storage facilities but also the underlying software-enabled communication infrastructure. FLAME's ecosystem will engage both the creative industries (broadcast, gaming, etc.) and ICT industries (telcos, services) responsible for online distribution, broadcast, communication, and distribution of digital content. Through acceleration methodologies and an advanced experimentation platform (surrogate service management, adaptive service routing, experimental media service chains and experimentation toolbox), FLAME will allow industry, SMEs and entrepreneurs to conduct experiments in real-life experimental infrastructures and gain insight into the performance, acceptance and viability of solutions. FLAME's innovation potential will be maximised by establishing FLAME Trailblazers (Bristol, Barcelona) to show the way for FLAME Replicators across Europe using a replication process based on best practice sustainability, governance, and engagement models, and infrastructure standards and specifications. A 3rd party investment strategy will create a vibrant FMI ecosystem that adds significant value to current FIRE+ efforts, and puts in place measures for long term sustainability.

Project Title	FUTEBOL: federated union of telecommunications research facilities for and EU-Brazil Open Laboratory
Lead Organisation	THE PROVOST, FELLOWS, FOUNDATION SCHOLARS & THE OTHER MEMBERS OF BOARD OF THE COLLEGE OF THE HOLY & UNDIVIDED TRINITY OF QUEEN ELIZABETH NEAR DUBLIN *
Partners	UNIVERSITY OF BRISTOL Teknologian tutkimuskeskus VTT Oy * INSTITUTO DE TELECOMUNICACOES *I INTEL DEUTSCHLAND GMBH *
Funding Source	H2020
Funding	€ 1,499,446
Start / End	01/03/2016 - 28/02/2019
5G Classification Terms	NFV, SDN, Optical Network, System Integration / Validation / Simulation
Weblink	http://www.ict-futebol.org.br/
Description (containing objectives, potential outcomes)	FUTEBOL composes a federation of research infrastructure in Europe and Brazil, develops a supporting control framework, and conducts experimentation-based research in order to advance the state of telecommunications through the investigation of converged optical/wireless networks. Current wireless trends (cell densification, coordinated communication, massive MIMO) pose a new set of challenges that require the joint consideration of optical and wireless

	network architectures. These problems are of direct impact to emerging economies such as Brazil, with highly heterogeneous infrastructure capabilities and demand, as well as to more established markets such as the EU, which aims to regain its leadership in the next generation of telecommunication technologies. FUTEBOL establishes the research infrastructure to address these research challenges through innovation over this infrastructure, with a consortium of leading industrial and academic telecommunications institutions. In this capacity, the methodology of the FUTEBOL project is organized into three steps: i) the composition of federated research infrastructure suited for integrated optical/wireless experimentation, ii) the development of a converged control framework to support experimentation on the federated research infrastructure, and iii) the direct advancement of telecommunications through research using the developed research infrastructure and control framework. The steps of FUTEBOL relate to one another in a layered manner: the end-user driven advancement of telecommunications relies on the development of the FUTEBOL converged control framework, which, in turn, requires the composition of federated research infrastructure. In this way, FUTEBOL directly addresses the agreed priority areas of Brazil and Europe cooperation to guide future innovation in the area of ICT. By leveraging and extending the prior work of the FIRE programme and FIBRE project, FUTEBOL expedites industry-centric innovation.

Project Title	5GINFire: Evolving FIRE into a 5G-oriented experimental playground for vertical industries
Lead Organisation	EURESCOM-EUROPEAN INSTITUTE FOR RESEARCH AND STRATEGIC STUDIES IN TELECOMMUNICATIONS GMBH *
Partners	B-COM * EASY GLOBAL MARKET SAS * INSTITUTO DE TELECOMUNICACOES * TELEFONICA INVESTIGACION Y DESARROLLO SA * UNIVERSIDAD CARLOS III DE MADRID * UNIVERSITY OF BRISTOL PANEPISTIMIO PATRON * FUNDACAO DE APOIO UNIVERSITARIO *I UNIVERSIDADE DE SAO PAULO *
Funding Source	H2020
Funding	€ 4,999,970
Start / End	01/01/2017 - 31/12/2019
5G Classification Terms	NFV, SDN, System Integration / Validation / Simulation, Automotive, IoT - Smart Cities
Weblink	https://5ginfire.eu/

Description (containing objectives, potential outcomes)	Key industrial sectors e.g. automotive, are rapidly transformed by digital and communication technologies leading to the fourth industrial revolution. New ones are in the making, e.g. Smart Cities, which inspire a new breed of applications and services. The salient characteristic of these sectors, known as verticals, is that they are rapidly becoming open ecosystems built on top of common physical infrastructures and resources. This requires a high degree of technological convergence among vertical industries empowering them with enhanced technical capacity to trigger the development of new, innovative products, applications and services. 5G network infrastructures and embodied technologies are destined to “become a stakeholder driven, holistic environment for technical and business innovation integrating networking, computing and storage resources into one programmable and unified infrastructure”. It is this 5G vision that when it is further projected to accommodate verticals raises a number of technical issues Motivated by them, 5GinFIRE project aspires to address two interlinked questions: - Q1: How such a holistic and unified environment should look like? - Q2: How can 5GinFIRE host and integrate verticals and concurrently deal with reconciling their competing and opposing requirements? Addressing these key questions, 5GinFIRE main technical objective is to build and operate an Open, and Extensible 5G NFV-based Reference (Open5G-NFV) ecosystem of Experimental Facilities that integrates existing FIRE facilities with new vertical-specific ones and enables experimentation of vertical industries. In order to guarantee architectural and technological convergence the proposed environment will be built in alignment with on-going standardization and open source activities. Accordingly, the Open5G-NFV FIRE ecosystem may serve as the forerunner experimental playground wherein innovations may be proposed before they are ported to emerging “mainstream” 5G networks.

Project Title	MATILDA: a holistic, innovative framework for design, development and orchestration of 5G-ready application and network services over sliced programmable infrastructure
Lead Organisation	CONSORZIO NAZIONALE INTERUNIVERSITARIO PER LE TELECOMUNICAZIONI *
Partners	ATOS SPAIN SA * ERICSSON TELECOMUNICAZIONI * INTRASOFT INTERNATIONAL SA * COSMOTE KINITES TILEPIKOINONIES AE * ORANGE ROMANIA SA * EXXPERTSYSTEMS GMBH * GIOUMPITEK MELETI SCHEDIASMOS YLOPOIISI KAI POLISI

	ERGON PLIROFORIKIS ETAIREIA PERIORISMENIS EFTHYNIS * INTERNET INSTITUTE, COMMUNICATIONS SOLUTIONS AND CONSULTING LTD * INCELLIGENT IDIOTIKI KEFALAIOUCHIKI ETAIREIA * SUITE5 DATA INTELLIGENCE SOLUTIONS LIMITED * NATIONAL CENTER FOR SCIENTIFIC RESEARCH "DEMOKRITOS" * UNIVERSITY OF BRISTOL AALTO-KORKEAKOULUSAATIO sr * UNIVERSITY OF PIRAEUS RESEARCH CENTER * ITALTEL SPA * BIBA - BREMER INSTITUT FUER PRODUKTION UND LOGISTIK GMBH *
Funding Source	H2020 (5G-PPP)
Funding	€ 6,664,458.75
Start / End	01/06/2017 - 30/11/2019
5G Classification Terms	NFV, SDN, Network Automation, Network Slicing, Massive / MU-MIMO
Weblink	http://www.matilda-5g.eu/
Description (containing objectives, potential outcomes)	The vision of MATILDA is to design and implement a holistic 5G end-to-end services operational framework tackling the lifecycle of design, development and orchestration of 5G-ready applications and 5G network services over programmable infrastructure, following a unified programmability model and a set of control abstractions. It aims to devise and realize a radical shift in the development of software for 5G-ready applications as well as virtual and physical network functions and network services, through the adoption of a unified programmability model, the definition of proper abstractions and the creation of an open development environment that may be used by application as well as network functions developers. Intelligent and unified orchestration mechanisms will be applied for the automated placement of the 5G-ready applications and the creation and maintenance of the required network slices. Deployment and runtime policies enforcement is provided through a set of optimisation mechanisms providing deployment plans based on high level objectives and a set of mechanisms supporting runtime adaptation of the application components and/or network functions based on policies defined on behalf of a services provider. Multi-site management of the cloud/edge computing and IoT resources is supported by a multi-site virtualized infrastructure manager, while the lifecycle management of the supported Virtual Network Functions Forwarding Graphs (VNF-FGs) as well as a set of network management activities are provided by a multi-site NFV Orchestrator (NFVO). Network and application-oriented analytics and profiling mechanisms are supported based on real-time as well as a posteriori processing of the collected data from a set of monitoring streams. The developed 5G-ready application components, applications,

	virtual network functions and application-aware network services are made available for open-source or commercial purposes, re-use and extension through a 5G marketplace.

Project Title	METRO-HAUL: High bandwidth, 5G application-aware optical network with edge storage, compute and low latency
Lead Organisation	BRITISH TELECOMMUNICATIONS PUBLIC LIMITED COMPANY
Partners	TELECOM ITALIA SPA * CENTRE TECNOLOGIC DE TELECOMUNICACIONS DE CATALUNYA * TELEFONICA INVESTIGACION Y DESARROLLO SA * UNIVERSITY OF BRISTOL UNIVERSITAT POLITECNICA DE CATALUNYA * CONSORZIO NAZIONALE INTERUNIVERSITARIO PER LE TELECOMUNICAZIONI * NAUDIT HIGH PERFORMANCE COMPUTING AND NETWORKING SL * OPENLIGHTCOMM LTD LEXDEN TECHNOLOGIES LTD ZEETTA NETWORKS LIMITED FRAUNHOFER GESELLSCHAFT ZUR FOERDERUNG DER ANGEWANDTEN FORSCHUNG E.V. * TECHNISCHE UNIVERSITEIT EIND * CORIANT PORTUGAL UNIPESSOAL LDA *I ERICSSON TELECOMUNICAZIONI * ADVA OPTICAL NETWORKING SE * NOKIA BELL LABS FRANCE * OLD DOG CONSULTING LIMITED SEETEC GMBH * ALCATEL-LUCENT ITALIA S.P.A. * POLITECNICO DI MILANO *
Funding Source	H2020 (5G-PPP)
Funding	€ 7,784,859.75
Start / End	01/06/2017 - 31/05/2020
5G Classification Terms	SDN, Optical Network, Qos/QoE, MEC (Mobile Edge Computing), Network Slicing
Weblink	https://metro-haul.eu/
Description (containing objectives, potential	METRO-HAUL is a project proposal addressing the Horizon 2020 ICT-07 5G PPP call; it is an RIA, focusing on strand 2 (high capacity elastic – optical networks) and strand 3 (software networks). The central topic is cost-efficient optical metro networks for 5G backhaul.

outcomes)	The aim of this project is to design and build a smart, but cost-effective, optical metro infrastructure able to support traffic originating from heterogeneous 5G access networks, addressing the anticipated capacity increase and its specific characteristics such as mobility, low latency, and high bandwidth. This infrastructure will be able to also support a wide variety of 5G applications with special emphasis on services from various industries vertical to the ICT. This will be achieved by architecting new access-facing and core-facing nodes, complete with storage and compute facilities, interconnected by novel, spectrally efficient, and adaptive optical transmission networks. Advanced concepts, such as hardware disaggregation and virtualisation, will assist in hitting challenging cost targets whilst enabling automation and programmability – all supported by a purpose-designed SDN-based control plane which will interface with client applications, intelligently catering for the wide range of 5G KPIs. METRO-HAUL will coordinate the disparate elements of transmission, switching, networking, compute, and storage, orchestrating dynamic solutions for multiple 5G applications. METRO-HAUL will carry out Proof of Concept demonstrations of its networking solution involving the interconnection of metro node prototypes, the use of the project's transmission technologies, and the associated control plane and orchestration software. The final project demonstrations will also involve the demonstration of actual 5G and vertical services across the METRO-HAUL test-bed. Additionally, the project will actively participate in the relevant standardization bodies, promoting METRO-HAUL solutions to the wider community

Project Title	5G PICTURE: 5G programmable infrastructure converging disaggraged network and compute resources
Lead Organisation	IHP GMBH - INNOVATIONS FOR HIGH PERFORMANCE MICROELECTRONICS/LEIBNIZ-INSTITUT FUER INNOVATIVE MIKROELEKTRONIK *
Partners	UNIVERSITY OF BRISTOL ADVA OPTICAL NETWORKING SE * AIRRAYS GMBH * BLU WIRELESS TECHNOLOGY LIMITED CONSORZIO NAZIONALE INTERUNIVERSITARIO PER LE TELECOMUNICAZIONI * COMSA INSTALACIONES Y SISTEMAS INDUSTRIALES SA * COSMOTE KINITES TILEPIKOINONIES AE * EURECOM * Ferrocarrils de la Generalitat de Catalunya * HUAWEI TECHNOLOGIES DUESSELDORF GMBH * FUNDACIO PRIVADA I2CAT, INTERNET I INNOVACIO DIGITAL A CATALUNYA * MELLANOX TECHNOLOGIES LTD - MLNX *

	TELECOM ITALIA SPA * TRANSPAKET AS * TECHNISCHE UNIVERSITAET DRESDEN * UNIVERSITAET PADERBORN * PANEPISTIMIO THESSALIAS * ZEETTA NETWORKS LIMITED
Funding Source	H2020 (5G-PPP)
Funding	€ 7,997,250
Start / End	01/06/2017 - 30/11/2019
5G Classification Terms	Media (AR/VR), EPC, Qos/QoE, NFV, SDN, Network Slicing, Optical Network, Cloud RAN, IoT - Smart Cities
Weblink	http://www.5g-picture-project.eu
Description (containing objectives, potential outcomes)	The explosive growth of mobile internet traffic introduces the need to transform traditional closed, static and inelastic network infrastructures into open, scalable and elastic ecosystems supporting new types of connectivity, high mobility and new mission-critical services for operators, vendors and vertical industries. 5G-PICTURE will develop and demonstrate a converged fronthaul and backhaul infrastructure integrating advanced wireless and novel optical network solutions. To address the limitations of the current D-RAN and C-RAN approaches, 5G-PICTURE will exploit flexible functional splits that can be dynamically selected, to optimise resource and energy efficiency. This results in a paradigm shift, from RAN and C-RAN to 'Dis-Aggregated RAN' (DA-RAN). DA-RAN is a novel concept where HW and SW components are disaggregated across the wireless, optical and compute/storage domains. 'Resource disaggregation' allows decoupling these components, creating a common "pool of resources" that can be independently selected and allocated on demand to compose any infrastructure service. Key enablers for DA-RAN are 1) network 'softwarization', migrating from the conventional closed networking model to an open reference platform, supported through 2) HW programmability, where HW is configured directly by network functions, to provide the required performance. This will enable provisioning of any service by flexibly mixing-and-matching network, compute and storage resources without sacrificing performance and efficiency as is the case in today's NFV-based solutions. To validate these capabilities, 5G-PICTURE will demonstrate converged fronthaul and backhaul services in: a) a smart city environment, b) a 5G railway experimental testbed showcasing seamless service provisioning and mobility management in high-speed moving environments and c) a stadium with ultra-high user density, supporting media services. The project results will be widely promoted for adoption and

	standardization

Project Title	mmMAGIC: Millimetre-wave based radio access networks for fifth generation integrated communications
Lead Organisation	SAMSUNG ELECTRONICS (UK) LIMITED
Partners	ERICSSON AB * AALTO-KORKEAKOULUSAATIO srl * ALCATEL-LUCENT DEUTSCHLAND AG * COMMISSARIAT A L ENERGIE ATOMIQUE ET AUX ENERGIES ALTERNATIVES * FRAUNHOFER GESELLSCHAFT ZUR FOERDERUNG DER ANGEWANDTEN FORSCHUNG E.V. * HUAWEI TECHNOLOGIES DUESSELDORF GMBH * INTEL DEUTSCHLAND GMBH * FUNDACION IMDEA NETWORKS * NOKIA SOLUTIONS AND NETWORKS SP ZO * NOKIA SOLUTIONS AND NETWORKS OY * ORANGE SA * TELEFONICA INVESTIGACION Y DESARROLLO SA * UNIVERSITY OF BRISTOL Qamcom Research and Technology AB * CHALMERS TEKNISKA HOEGSKOLA AB * KEYSIGHT TECHNOLOGIES DENMARK APS * ROHDE & SCHWARZ GMBH&CO * KOMMANDITGESELLSCHAFT * TECHNISCHE UNIVERSITAET DRESDEN *
Funding Source	H2020
Funding	€ 8,165,084
Start / End	01/07/2015 - 30/06/2017
5G Classification Terms	Propagation / Channel Modelling, mmWAVE, HetNets, Massive / MU-MIMO, Radio Front-end / RF
Weblink	https://5g-mmmagic.eu/
Description (containing objectives, potential outcomes)	The mmMAGIC (Millimetre-Wave Based Mobile Radio Access Network for Fifth Generation Integrated Communications) project will develop and design new concepts for mobile radio access technology (RAT) for mm-wave band deployment. This is envisaged as a key component in the 5G multi-RAT ecosystem and will be used as a foundation for global standardization. The project will thus enable ultrafast mobile broadband services for mobile users, supporting UHD/3D streaming, immersive applications and ultra-responsive cloud services. The consortium brings together major infrastructure vendors (Samsung, Ericsson, Alcatel-Lucent, Huawei, Intel, Nokia), major

	European operators (Orange, Telefonica), leading research institutes and universities (Fraunhofer HHI Institute, CEA-LETI, IMDEA Networks, Universities Aalto, Bristol, Chalmers and Dresden), measurement equipment vendors (Keysight Technologies, Rohde & Schwarz) and one SME (Qamcom). To complement its strong industry leadership and academic excellence, the project has an Advisory Board drawn from major European telecommunications regulators in Germany, France, Finland, Sweden and the UK. A new radio interface, including novel network management functions and architecture components will be proposed, taking as guidance 5G PPP's KPI and exploiting the use of novel adaptive and cooperative beam-forming and tracking techniques to address the specific challenges of mm-wave mobile propagation. The project will undertake extensive radio channel measurements in the 6-100 GHz range, and will develop and validate advanced channel models that will be used for rigorous validation and feasibility analysis of the proposed concepts and system, as well as for usage in regulatory and standards fora. The ambition of the project is to pave the way for a European head start in 5G standards, including 3GPP, and to secure essential IPRs to European industry, strengthening European competitiveness.

Project Title	5G-Xhaul: Dynamically Reconfigurable Optical-Wireless Backhaul/Fronthaul with Cognitive Control Plane for Small Cells and Cloud-RANs
Lead Organisation	IHP GMBH - INNOVATIONS FOR HIGH PERFORMANCE MICROELECTRONICS/LEIBNIZ-INSTITUT FUER INNOVATIVE MIKROELEKTRONIK *
Partners	FUNDACIO PRIVADA I2CAT, INTERNET I INNOVACIO DIGITAL A CATALUNYA * TELEFONICA INVESTIGACION Y DESARROLLO SA * UNIVERSITY OF BRISTOL PANEPISTIMIO THESSALIAS * BLU WIRELESS TECHNOLOGY LIMITED TES ELECTRONIC SOLUTIONS GMBH* COSMOTE KINITES TILEPIKOINONIES AE * TECHNISCHE UNIVERSITAET DRESDEN * AIRRAYS GMBH * HUAWEI TECHNOLOGIES DUESSELDORF GMBH * ADVA OPTICAL NETWORKING SE *
Funding Source	H2020 (5G-PPP)
Funding	€ 7,233,887.50
Start / End	01/07/2015 - 30/06/2018
5G Classification	NFV, SDN, Network Slicing, mmWAVE, Optical Network, Cloud RAN,

Terms	HetNets
Weblink	http://www.5g-xhaul-project.eu/project.html
Description (containing objectives, potential outcomes)	Small Cells, Cloud-Radio Access Networks (C-RAN), Software Defined Networks (SDN) and Network Function Virtualization (NVF) are key enablers to address the demand for broadband connectivity with low cost and flexible implementations. Small Cells, in conjunction with C-RAN, SDN, NVF pose very stringent requirements on the transport network. Here flexible wireless solutions are required for dynamic backhaul and fronthaul architectures alongside very high capacity optical interconnects. However, there is no consensus on how both technologies can be most efficiently combined. 5G-XHaul proposes a converged optical and wireless network solution able to flexibly connect Small Cells to the core network. Exploiting user mobility, our solution allows the dynamic allocation of network resources to predicted and actual hotspots. To support these novel concepts, we will develop: 1) Dynamically programmable, high capacity, low latency, point-to-multipoint mm-Wave transceivers, cooperating with sub-6-GHz systems; 2) A Time Shared Optical Network offering elastic and fine granular bandwidth allocation, cooperating with advanced passive optical networks; 3) A software-defined cognitive control plane, able to forecast traffic demand in time and space, and the ability to reconfigure network components. The well balanced 5G-XHaul consortium of industrial and research partners with unique expertise and skills across the constituent domains of communication systems and networks will create impact through: a) Developing novel converged optical/wireless architectures and network management algorithms for mobile scenarios; b) Introduce advanced mm-Wave and optical transceivers and control functions; c) Support the development of international standards through technical and techno-economic contributions. 5G-XHaul technologies will be integrated in a city-wide testbed in Bristol (UK). This will uniquely support the evaluation of novel optical and wireless elements and end-to-end performance.

Project Title	SESAME: Small cells coordination for multi-tenancy and edge services
Lead Organisation	HELLENIC TELECOMMUNICATIONS ORGANISATION S.A. - OTE AE (ORGANISMOS TILEPIKOINONION TIS ELLADOS OTE AE) *
Partners	IP.ACCESS LIMITED CREATE-NET (CENTER FOR RESEARCH AND

	TELECOMMUNICATION EXPERIMENTATION FOR NETWORKED COMMUNITIES) * FONDAZIONE BRUNO KESSLER * ITALTEL SPA * VIRTUAL OPEN SYSTEMS * UNIVERSITY OF SURREY ATOS SPAIN SA * UNIVERSITY OF BRIGHTON UNIVERSIDAD DEL PAIS VASCO/ EUSKAL HERRIKO UNIBERTSITATEA * ORION INNOVATIONS PRIVATE COMPANY * FUNDACIO PRIVADA I2CAT, INTERNET I INNOVACIO DIGITAL A CATALUNYA * NATIONAL CENTER FOR SCIENTIFIC RESEARCH "DEMOKRITOS" * STMICROELECTRONICS GRENOBLE 2 SAS FUJITSU LABORATORIES OF EUROPE LIMITED ZURCHER HOCHSCHULE FUR ANGEWANDTE WISSENSCHAFTEN * UNIVERSITAT POLITECNICA DE CATALUNYA * ATHONET SRL * INCITES CONSULTING SARL * SISTELBANDA SA * SMARTNET ANONYMI TOURISTIKI KAI KATASKEVASTIKI ETAIREIA PAROCHIS YPIRESION *
Funding Source	H2020
Funding	€ 7,488,432.76
Start / End	01/07/2015 - 31/12/2017
5G Classification Terms	NFV, MEC (Mobile Edge Computing), Cloud RAN, HetNets
Weblink	https://cordis.europa.eu/project/rcn/197343_en.html
Description (containing objectives, potential outcomes)	SESAME targets innovations around three central elements in 5G: the placement of network intelligence and applications in the network edge through Network Functions Virtualisation (NFV) and Edge Cloud Computing; the substantial evolution of the Small Cell concept, already mainstream in 4G but expected to deliver its full potential in the challenging high dense 5G scenarios; and the consolidation of multi-tenancy in communications infrastructures, allowing several operators/service providers to engage in new sharing models of both access capacity and edge computing capabilities. SESAME proposes the Cloud-Enabled Small Cell (CESC) concept, a new multi-operator enabled Small Cell that integrates a virtualised execution platform (i.e., the Light DC) for deploying Virtual Network Functions (NVFs), supporting powerful self-x management and executing novel applications and services inside the access network

	infrastructure. The Light DC will feature low-power processors and hardware accelerators for time critical operations and will build a high manageable clustered edge computing infrastructure. This approach will allow new stakeholders to dynamically enter the value chain by acting as 'host-neutral' providers in high traffic areas where densification of multiple networks is not practical. The optimal management of a CESC deployment is a key challenge of SESAME, for which new orchestration, NFV management, virtualisation of management views per tenant, self-x features and radio access management techniques will be developed. After designing, specifying and developing the architecture and all the involved CESC modules, SESAME will culminate with a prototype with all functionalities for proving the concept in relevant use cases. Besides, CESC will be formulated consistently and synergistically with other 5G-PPP components through coordination with the corresponding projects.

Project Title	MILLIBAN: Millimetre-wave antennas and components for future mobile broadband networks
Lead Organisation	University of Birmingham
Partners	University of Surrey BAE Systems BluWireless Technology Elite Antennas Ltd Plasma Antennas Ltd Samsung
Funding Source	EPSRC
Funding	£ 1,416,902
Start / End	23/03/2017 - 30/04/2020
5G Classification Terms	Radio Front-end / RF, mmWAVE, Antenna
Weblink	http://gow.epsrc.ac.uk/NGBOViewGrant.aspx?GrantRef=EP/P008380/1 http://gow.epsrc.ac.uk/NGBOViewGrant.aspx?GrantRef=EP/P008402/1
Description (containing objectives, potential outcomes)	Future mobile communication services will require exceptionally high data rates (over 10Gbits/s) to support more demanding user requirements, including High Definition video streaming. True mobile broadband is a major challenge for the telecommunications industry and urgently calls for radical new design approaches. The millimetre wave (mmWave) band (30GHz-300GHz), offers underexploited opportunities in terms of wide available bandwidths thus supporting high data throughput (e.g. multi-Gbps/Tbps) as well as enhanced data security. This is in sharp contrast to

	the dearth of spectrum in the congested sub-6GHz bands. In recent years there has been considerable interest in using mmWave technology in telecommunication applications. High performance cost-effective antennas with the ability to focus their radiated energy towards different directions are a crucial requirement for the successful deployment of envisaged mmWave mobile wireless networks. State-of-the-art mmWave antenna technology is unable to support this type of continuous beam steering with low power requirements and wide angular steering range. This imposes a major barrier to the successful development of the envisaged mmWave mobile networks. The interdisciplinary research described in this proposal will address this major problem. We will develop new paradigms in antenna design leading to breakthroughs in the analogue beamforming performance. This will be based on innovative enabling material technology along with state of the art microfabrication processes building on heritage at the applicants' institutions. The capabilities of the proposed antenna designs will be fully leveraged to maximize the system throughput with the optimized design of mmWave based small cell access techniques and realistic test-bed measurements which will demonstrate opportunities for significantly enhanced communication system throughput. The outcomes of this work would place the UK at the centre of developments in this transformative area. This joint proposal brings together two globally leading academic research institutes/centres having complementary experimental infrastructure and skills. Importantly, the proposal involves several key industrial partners who will help to shape the programme and shorten the lag between fundamental research and product development thus further increasing impact generation.

Project Title	Liquid-Crystal-Based Beam Steerable Planar Antennas for 60 GHz Wireless Networks
Lead Organisation	University of Essex
Partners	UCL
Funding Source	EPSRC
Funding	£ 779,912
Start / End	02/01/2011 - 01/07/2014
5G Classification Terms	Antenna
Weblink	http://gow.epsrc.ac.uk/NGBOViewGrant.aspx?GrantRef=EP/I003614/1

	http://gow.epsrc.ac.uk/NGBOViewGrant.aspx?GrantRef=EP/I003894/1
Description (containing objectives, potential outcomes)	The huge bandwidth available in the unlicensed 57-66 GHz spectrum can support multi-gigabit transmission. Depending on the operating environment and application, 60 GHz wireless networks with ranges between 10 m to 100 m are attractive and currently are under research and development. They can have immense applications in consumer and professional electronic markets. Not only do wireless networks eliminate cabling between communicating terminals, but they permit high definition (HD) uncompressed video streaming over air, can support wireless HD video interactive games, allow secure multi-gigabit data link between close city offices, and can provide safe and fast data, audio and video wireless distribution in planes, trains, cars, offices, hospitals and many other places of interests. Restricted to these applications alone, the sale of 60 GHz chipsets is estimated to run into billions of units. In the 60 GHz band the external interference is extremely low as the absorption of electromagnetic signals by oxygen and obstacles are extremely high. Unfortunately, the high attenuation together with the low transmitter power adversely affects the transmission quality. As flagged by the industry, this problem can be overcome by the implementation of directional antennas in 60 GHz transceivers, capable of steering their beams automatically for maximum signal reception. The aim of this work is to develop beam steerable planar antenna arrays for the 60 GHz band using nematic liquid crystals as a means for controlling the phase distribution over the antenna elements and hence, to provide prototype antennas which are compact, low-power and low-cost for multi-gigabit 60 GHz wireless networks. For this purpose, we will investigate, develop and compare two types of phase shifters based on liquid crystals, and design and build beam steering antenna arrays integrating the best alternative. Both the optimisation of the phase shifter performance and the development of the antenna arrays require detailed liquid crystal and electromagnetic modelling for which there is no commercial software available. In this work, our own advanced liquid crystal and electromagnetic modelling methods are extended and software tools capable of dealing with fully inhomogeneous and anisotropic dielectrics (on a point by point basis) will be developed in order to analyse and design accurately and reliably the 2D and 3D liquid-crystal-based devices including phase shifters and antennas.

Project Title	INSIGHT: Introducing Insight into the Abstraction of Optical Network Infrastructures
Lead Organisation	UCL
Partners	University of Bristol University of Cambridge BT Huber & Suhner
Funding	EPSRC

Source	
Funding	£ 758,099
Start / End	31/12/2014 - 31/01/2016
5G Classification Terms	Optical Network
Weblink	http://gow.epsrc.ac.uk/NGBOViewGrant.aspx?GrantRef=EP/L026155/1
Description (containing objectives, potential outcomes)	The unprecedented growth of optical fibre infrastructure in recent decades has underpinned telecommunications and the Internet, making possible broadband communications, e-commerce, video-on-demand and streaming media, tele-presence and high performance distributed computing. It has dramatically changed the whole landscape of public, business and government activities, stimulating relentless traffic growth. This necessitates a clear strategy to sustain the growth in information-carrying digital communications infrastructure. Infrastructure is the backbone of our economy digital communication infrastructure needs urgent attention since it underpins almost every aspect of economy and society. It should be flexible, adaptable, capable of continuous and smooth evolution with well-understood performance limits over its full life-cycle. This outline proposal addresses the first of the main cross cutting challenges of TI3 - The communications bottleneck. A future intelligent information infrastructure needs to intelligently manage massive amounts of data, to ensure efficient communications and exploit the content and information that will be available. It is in this context that we view this proposal as vital to the development of the future of information society. The role of fibre communications, providing the capacity for the lion's share of the total information traffic, is vital. However, to make the most efficient use of the optical fibre infrastructure requires that it can be accessed transparently, and on demand, by users, data, services and applications. To ensure this requires a completely different approach to the design of the communications infrastructure. It requires the optical resources (which include transmitters, receivers, fibre communication channels and routers) to be abstracted in a way to ensure the seamlessness of resource. The infrastructure will be treated as a service, accessible over the cloud. Optical layer capabilities such as capacity, latency, and spectrum availability could then be abstracted, become transparently accessible by using a unified interface. This requires the development of a new framework capable of uniformly representing and abstracting the heterogeneous optical resources in the optical layer, taking into account the various attributes and constraints of the optical infrastructure. Current optical network abstraction and virtualization research activities have focused on optical systems which are designed and optimised to have a fixed number of channels communicating at a given speed optimised over a defined set of distances. However, to maximise the use of optical infrastructure requires a flexible approach about how it is allocated, for how long and at what rate. The complexity and adaptability of advance optical communication systems (variable and adaptive modulation formats, rates,

	flexible nodes, etc.) pose numerous challenges on choosing the suitable description format and level of abstraction. Such process will simplify the control of underlying complex optical systems and in turn transparently provide services to the users with diverse business models and needs in a flexible, reconfigurable and intelligent. The framework developed in the course of will have insight about how to maximise the capacity of the infrastructure, whilst minimising energy and delay enabling transformational applications and services to be delivered intelligently and seamlessly.

Project Title	MACACO: mobile context-adaptive caching for content-centric networking
Lead Organisation	University of Birmingham
Partners	N/A
Funding Source	EPSRC
Funding	£ 284,801
Start / End	30/04/2014 - 31/05/2015
5G Classification Terms	Qos/QoE, MEC (Mobile Edge Computing), HetNets
Weblink	http://gow.epsrc.ac.uk/NGBOViewGrant.aspx?GrantRef=EP/L018829/1
Description (containing objectives, potential outcomes)	Finding new ways to manage the increased data usage and to improve the level of service required by the new wave of smartphones applications is an essential issue. The MACACO project proposes an innovative solution to this problem by focusing on data offloading mechanisms that take advantage of context and content information. Our intuition is that if it is possible to extract and forecast the behaviour of mobile network users in the three dimensional space of time, location and interest (i.e. 'what', 'when' and 'where' users are pulling data from the network), it is possible to derive efficient data offloading protocols. Such protocols would pre-fetch the identified data and cache them at the network edge at an earlier time, preferably when the mobile network is less congested, or offers better quality of service. Caching can be done directly at the mobile terminals, as well as at the edge nodes of the network (e.g., femtocells or wireless access points). Building on previous research efforts in the fields of social wireless networking, opportunistic communications and content networking, MACACO will address several issues in this space. The first one is to derive appropriate models for the correlation between user interests and

	their mobility. Lots of studies have characterised mobile nodes mobility based on real world data traces, but knowledge about the interactions with user interests in this context is still missing. To fill this gap, MACACO proposes to acquire real world data sets to model mobile node behaviour in the aforementioned three-dimensional space. The second issue addressed is the derivation of efficient data-offloading algorithms leveraging the large-scale data traces and corresponding models. Firstly, simple and efficient prediction algorithms will be derived to forecast the node's mobility and interests. Then, MACACO will provide data pre-fetching mechanisms that both improves the perceived quality of service of the mobile user and noticeably offloads peak bandwidth demands at the cellular network. A proof of concept will be exhibited through a federated testbed located in France, Switzerland and in the UK.

Project Title	Converged Optical and Wireless Access Networks (COALESCE)
Lead Organisation	UCL
Partners	Oclaro BT University of Oxford University of Southampton University of Cambridge
Funding Source	EPSRC
Funding	£ 1,373,034
Start / End	01/01/2017 - 31/12/2021
5G Classification Terms	Optical Network, Energy Efficiency
Weblink	http://gow.epsrc.ac.uk/NGBOViewGrant.aspx?GrantRef=EP/P003990/1
Description (containing objectives, potential outcomes)	For most users today, connecting to the Internet ("access") is done wirelessly, either by Wi-Fi or mobile data networks. Yet the unseen high-speed backbone of the Internet depends almost exclusively on fibre optic networks. To provide the higher data rate wireless access demanded by users to support increasingly sophisticated services and applications, wireless cell sizes must be reduced, presenting numerous challenges. One such challenge is how to distribute the signals to each radio access point. This problem will be exacerbated in future wireless networks operating at higher carrier frequencies in the millimetre-wave or sub-

	terahertz bands, due to greatly reduced propagation distances at these frequencies. One solution is to use radio-over-fibre techniques, using optical fibre to connect the central office or base station to the access points. Thus, the optical fibre will be pushed closer to the user, with radio providing only the final, short hop. As an alternative to radio, an optical signal could be used to make that last wireless link (optical wireless access), producing a scenario where the interconnection between the optical network and the wireless access is even more seamless. Another challenge brought about by the increased number of access points is that of energy consumption. Indeed, the biggest - and growing - contribution to energy consumption in the communications network is in the area of wireless access. Connecting the optical and wireless networks together in as seamless a manner as possible would offer advantages by reducing the energy lost in converting optical signals into wireless transmissions. This project aims to bring together key groups already carrying out work on various aspects of wireless access and optical networking. It will create a physical network to interconnect existing test-beds at the different universities, using an established research optical network - the National Dark Fibre Infrastructure Service. This will foster collaboration between the groups with their complementary expertise and encourage cross-fertilisation of ideas, with the aim of finding optimal solutions for different wireless access scenarios. Beyond the physical network of test-beds, it is planned that this consortium will form the core of a Network of Excellence of researchers working in this area, which will encourage and promote collaboration with and between other university and industrial groups, both in the UK and internationally.

Project Title	RC3: Robust Cognitive Cooperative Communications
Lead Organisation	UCL
Partners	BT WICO Shanghai Research Centre *
Funding Source	EPSRC
Funding	£ 315,750
Start / End	15/07/2013 - 14/07/2016
5G Classification Terms	Radio Front-end / RF, Baseband/ Signal processing, Massive / MU-MIMO
Weblink	http://gow.epsrc.ac.uk/NGBOViewGrant.aspx?GrantRef=EP/K015893/1

Description (containing objectives, potential outcomes)	According to the Ofcom's Digital Dividend report in 2007, spectrum is limited only because they are seriously underutilised due to rigid and inefficient management. It was reported that over 90% of locations could have around 100MHz of spectrum available for other services. These underutilised or unused spectrum holes, also known as white spaces, are mainly due to the interleaved spectrum for the digital TV band. Given the fact that the entire 3G spectrum is only 75MHz, this is an unacceptable wastage. At the same time, however, this gives golden opportunities for mobile operators, broadband service providers and users in the UK to improve the QoE for personal communications using cognitive transmission in the spectrum TV white spaces. In this context, BT is committed to exploiting the TV spectrum white spaces for providing wireless broadband access for homes in rural areas using cognitive radio (CR) technologies. According to BT, there are 2.75 million customers in rural areas, known as "not-spots" where, as ridiculous as it sounds, have no 3G coverage and Internet service is pretty much limited to dial-up access over residential or business telephone lines. In the "not-spots", the service is less than 2M bps but the TV spectrum white spaces, if utilised properly, can potentially cover more than 25% of the "not-spots" for improved services. The opportunity is that homes in a neighbourhood can share their antennas and signal processing capability to deliver much higher QoE using the spectrum white spaces at no extra cost. This project takes a novel perspective of enhancing the energy and spectrum efficiencies of wireless communications via user cooperation (e.g., multiple homes cooperation), which offers the possibility to improve the channel by sharing the resources between users. This exceptionally challenging objective has the potential to redefine the architecture of wireless networks, provide a novel system solution for extending the coverage and enhancing the QoE of broadband communications. In this project, the PI and BT (as the industrial partner) will join force to address the optimisation problem for cognitive cooperation. Our aim is to tackle the fundamental technical challenges specific to a cooperative MIMO channel. For instance, the required optimisation will need to take into account of individual users' requirements, constraints and fairness issues. Also, the proposed cooperative solution is also required to be robust to imperfect channel state information (CSI) and asynchronousity of the cooperating nodes, and be realised in a distributed manner. BT will be a key partner to provide invaluable inputs on the practical level to ensure that the project deliverables are exploitable. The final outcome of the proposed project will be the technologies for self-optimising cooperative antenna systems which can be used to provide broadband coverage for "not-spot" areas over wireless in the TV spectrum white spaces.

Project Title	INSP: the business and technical case for in-network service providers
Lead	UCL

Organisation	
Partners	N/A
Funding Source	EPSRC
Funding	£ 972,417
Start / End	31/03/2015 - 30/032020
5G Classification Terms	SDN, Routing, Business Models
Weblink	http://gow.epsrc.ac.uk/NGBOViewGrant.aspx?GrantRef=EP/M003787/1
Description (containing objectives, potential outcomes)	This project will design and implement all the required functionality to de-ossify the Internet architecture, which at the moment is limited to end-host-centric communication realised through end-host IP addresses. The IP protocol, which has become the thin-waist of the protocol stack, on the one hand guarantees a common language for communication between any network and any device, but on the other, restricts both communication and computation at the end-points of any connection. This further limits the Internet architecture from integrating new functionalities at the core of the network, unavoidably pushing innovation at the application layer. We argue that network functionality (in terms of content and service management) does not necessarily need to be pushed at the application-layer of the connection's end-points, but can instead be managed at the network-layer of mid-path network entities. To achieve our goals we will make use of the basic principles of two new networking paradigms, namely Information-Centric Networks (ICNs) and Software-Defined Networks (SDNs). ICNs introduce the notion of named-content objects and enable management of named-content at the network-layer (or data-plane) of any network device. SDNs on the other hand, focus on network management operations and push functionality at the control plane. Although both paradigms hold huge potential to change internetworking as we know it today, they both face implementation challenges. In this project, we will combine the functionality of ICNs and SDNs and take advantage of their novel concepts to design a new common Internet playground, where innovation will not be forcefully pushed at the application layer. We will follow pragmatic implementation routes to guarantee that the challenges faced in the areas of ICN and SDN are smoothly overcome. The high-level objectives of the project are the following: 1. implement and integrate the required technology to allow Internet

	Service Providers (ISPs) implement their own protocols of choice within their administrative domains, allowing for de-ossification of the Internet architecture. 2. allow in-network entities to execute logic and run instances of applications mid-path from source to destination, which are otherwise run within data-centres, more often than not, far away from the end-users. The above targets will be achieved by introducing a new Internet market player, which we call In-Network Service Provider (or INSP) and who will take on the task (and cost) of implementing the proposed functionality.

Project Title	KCN: Knowledge Centric Networking
Lead Organisation	UCL
Partners	University of Bristol University of Surrey NEC BBC MobileVCE
Funding Source	EPSRC
Funding	£ 982,915
Start / End	31/12/ 2014 - 30/06/2018
5G Classification Terms	SDN, Energy Efficiency, MEC (Mobile Edge Computing)
Weblink	http://gow.epsrc.ac.uk/NGBOViewGrant.aspx?GrantRef=EP/L026120/1
Description (containing objectives, potential outcomes)	The recent advent of killer applications such as content distribution, cloud computing and Internet of things (IoT), all require for the underlying network to be able to understand specific service contexts. In this project we propose the Knowledge Centric Networking (KCN) paradigm, in which knowledge is positioned at the centre of the networking landscape. The objective is to enable in-network knowledge generation and distribution in order to develop necessary network control intelligence for handling complexity and uncertainty. In order to achieve this, specific algorithms and mechanisms/protocols will be developed for knowledge acquisition, processing, dissemination and organisation both within single and across homogeneous/heterogeneous administrative domains in the Internet. The project will investigate three styles of knowledge exchange based on Software Defined Networking (SDN) principles: Knowledge as a Tool

	(KaaT), Knowledge as a Service (KaaS) and Knowledge as a Cloud (KaaC). KaaT will enable intelligent network operations in dynamic network environments driven by knowledge gathered at different vantage points. We advocate a hierarchical knowledge framework in which knowledge and control functions are distributed at the right places within the network for fulfilling specific control tasks. In addition, we will investigate knowledge sharing between different players in the Internet marketplace. This can be achieved either through explicit knowledge transfer from a knowledge provider to a knowledge consumer (KaaS), or based on open knowledge clouds where knowledge prosumers may publish or subscribe to information through an open but controlled knowledge ecosystem (KaaS). The proposed KCN architecture will be validated through two complementary use cases. KCN-driven content traffic offloading between heterogeneous radio access technologies for the future mobile Internet aims to achieve adaptive resource control by taking into account a wide variety of knowledge associated with content, users and network conditions. In addition, KCN-driven energy management targets cross-layer energy saving techniques at both the IP and the physical optical layer according to the derived knowledge and dynamically changing context information. The project provides direct contributions to the TI3 sub-challenges 1, 2, 3 and 4. First of all, the KCN-based knowledge ecosystem will equip the next generation Internet with necessary intelligence for handling complex requirements under dynamic conditions. Such an ecosystem, seamlessly coupled with the SDN architecture, will be able to gracefully support the ever increasing complexity and heterogeneity of future networked services and multitude of users. The two complementary use cases demonstrate how the proposed KCN framework will be instantiated in two different application domains, content traffic offloading in mobile/wireless access networks and energy efficiency in IP/optical transport networks. Use case 1 contributes to the 3rd sub-challenge, with knowledge-based content caching and traffic offloading techniques for the future content-oriented mobile Internet. Use case 2, on the other hand, contributes to the 2nd sub-challenge with intelligent energy saving mechanisms at both the IP and optical layer. Finally, with in-network knowledge inference and learning based on raw context information, the project also addresses the 4th sub-challenge of extracting understanding from data. In summary, context information captured during network/service operation will be used to derive systematic in-network knowledge and intelligence in order to deal adaptively with both complexity and uncertainty and enable near-optimal network operation.

Project Title	NDFIS: National Dark Fibre Infrastructure Service
Lead Organisation	UCL
Partners	University of Bristol

	University of Southampton University of Cambridge
Funding Source	EPSRC
Funding	£2,500,000
Start / End	01/11/2013 - 31/10/2018
5G Classification Terms	SDN, Optical Network
Weblink	http://www.ndfis.org/
Description (containing objectives, potential outcomes)	The National Dark Fibre Infrastructure Service (NDFIS) is an Engineering and Physical Sciences Research Council (EPSRC) Facility, established in 2014, to enable researchers to develop the underpinning communications technologies for the future internet. FA 5 year contract for NDFIS has been awarded to UCL as prime contractor for a consortium comprising the Universities of Bristol, Cambridge and Southampton. NDFIS provides access to a dedicated dark fibre network connecting these universities, with onward connection to European and Worldwide research networks via telecommunications facilities in London. The network is engineered with equipment that can be configured remotely and, as part of the contract, techniques and software are being developed to enable its operation as a pioneering example of a Software Defined Network (SDN). The fibre paths linking the Universities, comprising some 640 km of single mode fibre together with control and monitoring links, are provided to NDFIS by Janet, part of the JISC group, funded by BIS through its e-Infrastructure programme. Researchers in the UK are able to access the new network, named Aurora2, both directly by placing equipment at consortium sites and remotely using the Janet Lightpath service. Dark fibre is optical fibre that users can access at the optical data level, rather than the electrical data level as in conventional communications networks. Access at the optical level enables users to experiment with novel communication techniques, such as high order optical modulation or quantum communication. NDFIS offers programmable transmission parameters, dynamic reconfiguration into multiple sub--networks and the ability to handle multiple transmission formats simultaneously. As well as supporting research on the future core optical network, which underpins the internet, NDFIS also enables research with experimental metro networks, such as the Gigabit Bristol network. NDFIS can also support research on wireless backhaul networks for future Wireless Systems such as 5G. NDFIS provides a key resource to researchers developing the future wireless and optical communications systems that will underpin the future internet.

Project Title	CI-PHY: Exploiting interference for physical layer security in 5G networks
Lead Organisation	UCL
Partners	BT National Instruments QinetiQ Huawei Technologies
Funding Source	EPSRC
Funding	£ 626,096
Start / End	01/02/2018 - 31/01/2021
5G Classification Terms	Security, Radio Front-end / RF
Weblink	http://gow.epsrc.ac.uk/NGBOViewGrant.aspx?GrantRef=EP/R007934/1
Description (containing objectives, potential outcomes)	Security and privacy have become a paramount concern in modern ICT, as threats from cybercrime are soaring. This year's global economic crime survey conducted by PwC reported that cybercrime has jumped from 4th to 2nd place among the most-reported types of economic crime. The severity of threat on the business, financial, infrastructure and other UK sectors makes all facets of security and risk management pertinent, and their importance cannot be overstated. Physical layer security (PS) provides an extra layer of security on top of the traditional cryptographic measures. It obstructs access to the wireless traffic itself, thus averting any higher layer attack. Encompassing a number of key technologies spanning secure beamforming, artificial noise design, network coding, cooperative jamming, graph theory, and directional modulation, PS is now commonly accepted as one of the most effective forms of security. While appealing as a theoretical concept, PS still faces a number of critical challenges that prevent it from wide commercial adoption in 5G and beyond, involving the lack of secure 5G signalling, the provision of eavesdroppers' information, and the applicability of existing theoretical techniques in real environments and under low-specification hardware. CI-PHY addresses the abovementioned challenges, and promotes a paradigm shift on security by exploiting interference. In particular, CI-PHY exploits constructive interference for Physical Layer Security by: - Specifically tailored fundamental waveform design to exploit interference, that provides a low complexity solution with limited hardware requirements; - Artificial noise and jamming to actively improve the desired receivers' SNR under secrecy constraints, and further improve secrecy by designing the artificial noise to align destructively to the signal at the

	eavesdropper; - Robust approaches for real implementation by taking hardware impairments into account to reduce the hardware requirements for providing secrecy with resource-constrained devices; - Real implementation and over-the-air testing of security solutions to evaluate and optimise performance in commercially relevant environments. CI-PHY will be performed with the Interdisciplinary Centre for Security, Reliability and Trust in University of Luxembourg, and industrial partners QinetiQ, BT, National Instruments and Huawei, and aspires to kick-start an innovative ecosystem for high-impact players among the infrastructure and service providers of ICT to develop and commercialize a new generation of secure and power-efficient communication networks, and address the unprecedented vulnerability of emerging ICT services to cyber threats.

Project Title	ALIEN: Abstraction layer for implementation of extensions in programmable networks
Lead Organisation	INSTYTUT CHEMII BIOORGANICZNEJ POLSKIEJ AKADEMII NAUK *
Partners	BISDN GMBH - BERLIN INSTITUTE FOR SOFTWARE DEFINED NETWORKS * EUROPEAN CENTER FOR INFORMATION AND COMMUNICATION TECHNOLOGIES GMBH * UNIVERSIDAD DEL PAIS VASCO/ EUSKAL HERRIKO UNIBERTSITATEA * DELL FRANCE SA * CREATE-NET (CENTER FOR RESEARCH AND TELECOMMUNICATION EXPERIMENTATION FOR NETWORKED COMMUNITIES) * POLITECHNIKA POZNANSK UNIVERSITY COLLEGE LONDON UNIVERSITY OF BRISTOL
Funding Source	FP7
Funding	€ 1,450,000
Start / End	01/01/2012 - 30/09/2014
5G Classification Terms	SDN, System Integration / Validation / Simulation
Weblink	https://cordis.europa.eu/project/rcn/105633_en.html

Description (containing objectives, potential outcomes)	ALIEN will deliver an innovative network abstraction mechanism targeting the control and management convergence and interoperability of heterogeneous network elements building strong foundations for Software Defined Networks. To achieve this, ALIEN proposes to adopt the concept of Network Operating System (NOS), a distributed system running on top the hybrid, heterogeneous network infrastructure, which creates a global view of the network elements and their capability. The NOS of ALIEN will be based on control and management framework of OFELIA FIRE facility. ALIEN will extend OpenFlow control framework of OFELIA and its architecture to support abstraction of network information of equipment that are alien to the OpenFlow technology such as optical network elements, legacy layer2 switches, network processors and programmable hardware (FPGA).Building on its novel NOS, ALIEN introduces the concept of the control program paradigm, which operates on the global view of the network. and support new network technologies in layer0, layer1 and layer 2 both in core and access. The NOS of ALIEN utilizes a novel hardware description language as well as a functional abstraction mechanism for uniform representation of any type of network hardware and their capabilities/functionalities that doesn't support OpenFLow (i.e. alien hardware). The language will describe capabilities of hardware, input and output signal format, and topology information to describe the pipelining of actions on specific hardware. The abstraction mechanism will hide hardware complexity as well as technology and vendor specific features from OpenFlow control framework. ALIEN project aims to experimentally verify its solution for describing network device capabilities and controlling its forwarding behaviour of all OpenFlow and non-OpenFlow capable hardware simultaneously.

Project Title	TRIANGLE: 5G Applications and devices benchmarking
Lead Organisation	KEYSIGHT TECHNOLOGIES BELGIUM *
Partners	KEYSIGHT TECHNOLOGIES DENMARK APS * UNIVERSIDAD DE MALAGA * REDZINC SERVICES LIMITED * UCL DEKRA TESTING AND CERTIFICATION SAU * QUAMOTION *
Funding Source	H2020
Funding	€ 2,903,690
Start / End	01/01/2016 - 31/12/2018
5G Classification Terms	System Integration / Validation / Simulation, Qos/QoE, EPC, NFV, MEC (Mobile Edge Computing), SDN, System Integration / Validation / Simulation, Qos/QoE, EPC, NFV, SDN

Weblink	http://www.triangle-project.eu/
Description (containing objectives, potential outcomes)	The focus of TRIANGLE is the development of a framework that facilitates the evaluation of the QoE of new mobile applications, services and devices designed to operate in the future 5G mobile broadband networks. The framework will exploit existing FIRE facilities adding new facilities when necessary. The project will identify reference deployment scenarios, will define new KPIs (Key Performance Indicators) and QoE metrics, will develop new testing methodologies and tools, and will design a complete evaluation scheme. The project will focus on the development of a framework to ensure user QoE in the new challenging situations, especially those due to heterogeneous networks and considering the role software will have in the new 5G ecosystem. The framework as value added will also provide the means to allow certification and quality mark for the applications, services and devices compliant to the requirements and test specifications developed in the project but also extensible to other FIRE test solutions. This will allow vendor differentiation, specially start-ups and SMEs, in the current globalized and competitive markets and further visibility of FIRE facilities. The framework, methods and tools developed during the project will focus on providing the mechanisms to incorporate new wireless technologies and topologies envisaged in 5G and contribute to the new ecosystem.

Project Title	5GMedia: Programmable edge-to-cloud virtualization fabric for 5G media industry
Lead Organisation	ENGINEERING - INGEGNERIA INFORMATICA SPA *
Partners	IBM ISRAEL - SCIENCE AND TECHNOLOGY LTD * SINGULARLOGIC ANONYMI ETAIREIA PLIROFORIAKON SYSTIMATON KAI EFARMOGON PLIROFORIKIS * HELLENIC TELECOMMUNICATIONS ORGANISATION S.A. - OTE AE (ORGANISMOS TILEPIKOINONION TIS ELLADOS OTE AE) * CORPORACION DE RADIO Y TELEVISION ESPANOLA SA * UCL TELEFONICA INVESTIGACION Y DESARROLLO SA * UNIVERSIDAD POLITECNICA DE MADRID * INSTITUT FUR RUNDFUNKTECHNIK GMBH * NEXTWORKS * ETHNIKO KENTRO EREVNAS KAI TECHNOLOGIKIS ANAPTYXIS * NETAS TELEKOMUNIKASYON ANONIM SIRKETI * INTERINNOV SAS * BITTUBES GMBH
Funding Source	H2020 (5G-PPP)

Funding	€ 6,128,531.14
Start / End	01/06/2017 - 30/11/2019
5G Classification Terms	Media (AR/VR), NFV, Routing, Qos/QoE, MEC (Mobile Edge Computing), Network Slicing
Weblink	http://www.5gmedia.eu/
Description (containing objectives, potential outcomes)	The focus of 5G PPP H2020 remarkable research so far has been largely on the required advances in network architectures, technologies and infrastructures. Less attention has been put on the applications and services that will make use of and exploit advanced 5G network capabilities. 5G-MEDIA aims at innovating media-related applications by investigating how these applications and the underlying 5G network should be coupled and interwork to the benefit of both. In this respect, 5G-MEDIA addresses the objectives of 1) capitalizing and properly extending the valuable outcomes of the running 5G PPP projects to offer an agile programming, verification and orchestration platform for services, and 2) developing network functions and applications to be demonstrated in large-scale deployments, based on 3 well-defined use cases (in the areas of immersive media and VR, smart production and user-generated content, and UHD over CDN) of diverse requirements and particular interest for the consortium partners. Based on the adoption of the open innovation approach, 5G-MEDIA platform will be offered to third parties to develop, combine, verify, deploy and validate media applications by utilizing the SDK capabilities and Service Platform offerings. Finally, 5G-MEDIA plans to create an ambitious business impact with the introduction of Streaming as a Service concept, built on top of a well-defined, consortium-wide exploitation plan and supported by the complementarity of expertise of its consortium, representing key industrial sectors in the network and media domains: telecom operators (OTE, TID), cloud providers (SILO), PaaS/SaaS vendors (IBM), service providers (ENG), application developers (NETAS), broadcasters (RTVE), SMEs (IINV, NXW, IRT, BIT) and research centres (UCL, UPM, CERTH). It is highlighted that the consortium includes partners with strong and active participation in 5G-PPP programme, complemented by new but important players on the media & entertainment industry sector.

Project Title	SONATA: Service programming and orchestration of virtualised software networks
Lead Organisation	ATOS SPAIN SA *
Partners	NEC EUROPE LTD ALTICE LABS SA * THALES COMMUNICATIONS & SECURITY SAS *

	TELEFONICA INVESTIGACION Y DESARROLLO SA * ALCATEL-LUCENT ISRAEL LTD * UNIVERSITAET PADERBORN * NATIONAL CENTER FOR SCIENTIFIC RESEARCH "DEMOKRITOS"* UCL INTERUNIVERSITAIR MICRO-ELECTRONICA CENTRUM * IMINDS * OPTARE SOLUTIONS SL * FUNDACIO PRIVADA I2CAT, INTERNET I INNOVACIO DIGITAL A CATALUNYA * SYNELIXIS LYSEIS PLIROFORIKIS AUTOMATISMOU & TILEPIKOINONION MONOPROSOPI EPE * BRITISH TELECOMMUNICATIONS PUBLIC LIMITED COMPANY UBIWHERE LDA *
Funding Source	H2020 ((5G-PPP)
Funding	€ 6,657,721.38
Start / End	01/07/2015 - 31/12/2017
5G Classification Terms	NFV, SDN, Network Automation, Network Slicing, System Integration / Validation / Simulation, EPC, Security
Weblink	http://www.sonata-nfv.eu/
Description (containing objectives, potential outcomes)	Virtualisation and software networks are a major disruptive technology for communications networks, enabling services to be deployed as software functions running directly in the network on commodity hardware. However, deploying the more complex user-facing applications and services envisioned for 5G networks presents significant technological challenges for development and deployment. SONATA addresses both issues. For service development, SONATA provides service patterns and description techniques for composed services. A customised SDK is developed to boost the efficiency of developers of network functions and composed services, by integrating catalogue access, editing, debugging, and monitoring analysis tools with service packaging for shipment to an operator. For deployment, SONATA provides a novel service platform to manage service execution. The platform complements the SDK with functionality to validate service packages. Moreover, it improves on existing platforms by providing a flexible and extensible orchestration framework based on a plugin architecture. Thanks to SONATA’s platform service developers can provide custom algorithms to steer the orchestration of their services: for continuous placement, scaling,

	life-cycle management and contextualization of services. These algorithms are overseen by executives in the service platform, ensuring trust and resolving any conflict between services. By combining rapid development and deployment in an open and flexible manner, SONATA is realising an extended Davos model for network stakeholders. SONATA validates its approach through novel use-case-driven pilot implementations and disseminates its results widely by releasing its key SDK and platform components as open source software, through scientific publications and standards contributions, which, together, will have a major impact on incumbent stakeholders including network operators and manufacturers and will open the market to third-party developers.

Project Title	5GeX: 5G Exchange
Lead Organisation	Ericsson *
Partners	UCL ATOS SPAIN SA * ATHENS UNIVERSITY OF ECONOMICS AND BUSINESS - RESEARCH CENTER * BISDN GMBH - BERLIN INSTITUTE FOR SOFTWARE DEFINED NETWORKS * BUDAPESTI MUSZAKI ES GAZDASAGTUDOMANYI EGYETEM * DEUTSCHE TELEKOM AG * EUROPEAN CENTER FOR INFORMATION AND COMMUNICATION TECHNOLOGIES GMBH * ERICSSON TELECOMUNICAZION * HEWLETT PACKARD ITALIANA SRL * HUAWEI TECHNOLOGIES DUESSELDORF GMBH * KUNGLIGA TEKNISKA HOEGSKOLAN * ORANGE SA * REDZINC SERVICES LIMITED * TELECOM ITALIA SPA * TELENOR ASA * TELEFONICA INVESTIGACION Y DESARROLLO SA * UNIVERSIDAD CARLOS III DE MADRID * MEDIA NETWORK SERVICES AS *
Funding Source	H2020 (5G-PPP)
Funding	€ 7,921,094.88
Start / End	01/10/2015 - 31/03/2018
5G Classification	NFV, SDN, Network Automation, Network Slicing, System Integration / Validation / Simulation

Terms	
Weblink	https://cordis.europa.eu/project/rcn/197346_en.html
Description (containing objectives, potential outcomes)	The goal of the 5G Exchange (5GEx) project is to enable cross-domain orchestration of services over multiple administrations or over multi-domain single administrations. This will allow end-to-end network and service elements to mix in multi-vendor, heterogeneous technology and resource environments. Market fragmentation has resulted in a multitude of network operators each focused on different countries and regions. This makes it difficult to create infrastructure services spanning multiple countries, such as virtual connectivity or compute resources, as no single operator has a footprint everywhere. 5GEx aims to enable collaboration between operators, regarding 5G infrastructure services, with the view to introducing a unification via NFV/SDN compatible multi-domain orchestration by producing (i) an open platform enabling cross-domain orchestration of services over these multiple domains, with a set of open source software tools and extensions that can be utilised outside the scope of 5GEx; (ii) a Sandbox Network enabling experimentation and validation of the devised architecture, mechanisms, and business models; (iii) a proof-of-innovation multi-domain platform enabling multiple 5G use-cases and realistic scenarios that demonstrate the orchestration of complex end-to-end Infrastructure as a Service across multiple carriers; (iv) contributions to standards bodies of concepts learned during the development and experimentation of the project; (v) input to stimulate the telecom and IT industry stakeholders by actively promoting adoption of 5GEx's open solutions. Such 5G infrastructure services will provide a crucial role in making 5G happen as they provide the foundation of all cloud and networking services. 5GEx aims to enable, through operator collaboration, a unified European infrastructure service market integrating multiple operators and technologies, where service provisioning is fast and automated and which results in stronger economy via economies of scale.

Project Title	HUB4NGI: A Collaborative Platform to Unlock the Value of Next Generation Internet Experimentation
Lead Organisation	MARTEL GMBH *
Partners	UNIVERSITY OF SOUTHAMPTON THE OPEN UNIVERSITY IDC ITALIA SRL * INSTYTUT CHEMII BIOORGANICZNEJ POLSKIEJ AKADEMII NAUK *

	INTERUNIVERSITAIR MICRO-ELECTRONICA CENTRUM*
Funding Source	H2020
Funding	€ 999,565
Start / End	01/01/2017 - 31/12/2018
5G Classification Terms	Other
Weblink	https://www.hub4ngi.eu/
Description (containing objectives, potential outcomes)	The main goal of the HU4NGI project is to bootstrap the current Next Generation Internet (NGI) initiative and turn it into a dynamic, collaborative, and participatory innovation ecosystem capable of more effectively supporting and coordinating activities across the whole R&D landscape. The main idea is to build on top of the results and major achievements of ongoing Research and Innovation initiatives and projects, while giving a major impulse to the whole NGI community by providing an interactive framework that will assist the target stakeholders, including new comers and outside players in related domains, via a unique set of tools and mechanisms. The selected coordination and support tools and mechanisms will be at the core of the NGI ecosystem, which will offer and online collaboration environment to facilitate exchange and promotion of know-how, technical activities to be coordinated, strategic liaisons to be established and managed, performance and progress for the overall NGI initiative to be monitored and assessed.

Project Title	Smart Bandages
Lead Organisation	Swansea University
Partners	Welsh Wound Innovation Centre
Funding Source	Swansea Bay City deal
Funding	N/A
Start / End	N/A
5G Classification Terms	IoT - Health
Weblink	http://www.swansea.ac.uk/media-centre/latest-research/swanseauniversitysmartbandagetobetrialledwithin12months.php

Description (containing objectives, potential outcomes)	Swansea University's Institute of Life Science is leading research into the trial of bandages which use real-time 5G technology to monitor how a wound is healing and help doctors keep track of patient's activity levels.

Project Title	Autonomous device-to-device communications for secure, power internet-of-things
Lead Organisation	Queen's University of Belfast
Partners	N/A
Funding Source	EPSRC
Funding	N/A
Start / End	N/A
5G Classification Terms	D2D, IoT - Industry 4.0, IoT - Smart Cities, Security
Weblink	N/A
Description (containing objectives, potential outcomes)	PhD Studentship on D2D networks for Power-IoT systems. This project has four main objectives: (i) Creation of simpler, autonomous D2D realisation structure. (ii) Derivation of physical layer secured D2D in Power-IoT. (iii) Integrated multiple access and D2D features to advance the performance of Power-IoT, in ultra-dense, and non-conventional fading environments. (iv) Realisation of prototyping algorithms in hardware experiments.

Project Title	Low-Complexity processing for mmWave massive MIMO
Lead Organisation	Queen's University of Belfast
Partners	University of Edinburgh Huawei Technologies * University of Utah *
Funding Source	EPSRC
Funding	£ 996,628
Start / End	01/03/2017 - 29/02/2020
5G Classification	Massive / MU-MIMO, Baseband/ Signal processing, Energy Efficiency

Terms	
Weblink	http://gow.epsrc.ac.uk/NGBOViewGrant.aspx?GrantRef=EP/P000673/1 http://gow.epsrc.ac.uk/NGBOViewGrant.aspx?GrantRef=EP/P000703/1
Description (containing objectives, potential outcomes)	There are more than five billion wirelessly connected mobile devices in service today, most of which are handheld terminals or mobile-broadband devices such as computers and tablets. By 2020, mobile communications data traffic is expected to increase 1,000-fold, by which time there will be an estimated 50 billion Internet-capable devices. This transition will present a formidable challenge. Improving the energy efficiency (EE) of existing telecommunication networks is not just a necessary contribution towards the fight against global warming, but with the inevitable increases in the price of energy, it is becoming also a financial imperative. Future technologies (e.g. 5G) on which these devices will operate will require dramatically higher data rates and will consume far more power, and as a consequence increase their environmental footprint. To mitigate this, significant network densification, that is increasing the number of antennas per unit area, seems inevitable. To this end, a novel technological paradigm, known as massive MIMO, considers the deployment of hundreds of low-power antennas on the base station (BS) site to provide enhanced performance, reduced energy consumption, and better reliability. At the same time, the spectrum scarcity in the RF bands has stimulated a lot of research effort into mm-wave frequencies (30 to 300GHz). These frequencies offer numerous advantages: massive bandwidth/data rates, reduced RF interference, narrow beamwidths. The combination of the above technologies gives rise to mm-Wave massive MIMO, which is considered by many experts as the 'next big thing in wireless'. This paradigm shift avails of the vast available bandwidth at mm-frequencies, smaller form factors than designs implemented at current frequencies, reduced RF interference, channel orthogonality, and large beamforming/multiplexing gains. Yet, the practical design of mm-Wave massive MIMO faces many fundamental challenges, in respect of total energy consumption, circuitry cost, digital signal processing among others. In the context of the project, we envision a mm-wave massive MIMO topology performing a fraction of processing in the baseband (digital) and the remaining fraction in the RF band (analogue), with a reduced number of RF chains, to effectively address most of these challenges. In addition, by deploying low-resolution (coarse) analog-to-digital converters (ADCs), we can substantially reduce the power dissipation of mm-Wave massive MIMO transceivers. This visionary project will investigate the realisable potential of hybrid processing and 1-bit ADC quantisation. The specific project goals will be to: (a) find the optimal balance between analogue and digital processing for future MIMO configurations in order to maximise the end-to-end EE and experimentally validate the proposed solution, and; (b) investigate the realisable potential of 1-bit ADC quantisation and the channel estimation/resource allocation challenges it induces.

	By bringing together a world leading research team with expertise in communications engineering, signal processing, microwave engineering and antenna theory, and with the technical support of the biggest telecom equipment manufacturer in the world, Huawei Technologies Ltd, we will devise scalable low-complexity, low-power solutions suitable for the new generation of BS. We will investigate the algorithms and hardware that will optimise the performance of future BS to precisely meet performance and QoS targets, allied to minimum energy consumption. The application of the project results will contribute to the reduction of the ICT sector's contribution to global warming, through reduced power consumption and improved EE of future BSs. It will also influence many dynamic economic sectors within the UK: telecom equipment manufacturing, telecom operators, positioning systems, surveillance sector, smart cities, e-health, military equipment and automotive companies.

Project Title	HELOPA: High-efficiency low-cost power amplifiers for millimetre-wave massive MIMO systems
Lead Organisation	Queen’s University Belfast
Partners	Catena Holding
Funding Source	EPSRC
Funding	£100,493.00
Start / End	01/06/2016 - 31/12/2018
5G Classification Terms	Massive / MU-MIMO, mmWAVE, Energy Efficiency
Weblink	http://gow.epsrc.ac.uk/NGBOViewGrant.aspx?GrantRef=EP/P013031/1
Description (containing objectives, potential outcomes)	The dramatic improvements in capacity (as much as 1000x the current level) and spectral efficiency that are needed for future wireless communication systems to accommodate the rapidly increasing number of wireless electronic gadgets and users who require access to ubiquitous high-speed wireless links can be achieved by adopting mm-wave (mmW) massive multiple-input multiple-output (MIMO) technologies. The realization of mmW massive MIMO requires a radical change in base station architecture wherein hundreds of power amplifiers are required to feed a large array of small antennas. The development of mmW massive MIMO transceivers has been hampered to date by the power amplifier's (PA) poor efficiency and high implementation cost. Nonlinear switch-mode power amplifiers (SMPAs) such as Class E and F offer high efficiency but require fast (power-hungry, expensive) transistors to allow the generation of higher order harmonics. Moreover, an abrupt drop during ON-to-OFF or OFF-to-ON transition in the idealised switch current or voltage waveform of existing SMPA topologies results in substantial power dissipation in the

	practical implementation, and hence reduces the PA efficiency. The proposed research ambitiously aims to produce a new type of highly-efficient, highly-linear power amplifier that offers true soft-switching characteristics to permit the use of low-cost, slow-switching transistors for effective deployment in mmW massive MIMO systems and thus open the way for very power-conservative high-performance systems.

Project Title	Multi-Carrier Intext Keying for Next Generation Gigabit Wireless Communications
Lead Organisation	Queen's University Belfast
Partners	Samsung
Funding Source	EPSRC
Funding	£ 92,911
Start / End	29/06/2015 - 30/11/2016
5G Classification Terms	Radio Front-end / RF, Baseband/ Signal processing
Weblink	http://gow.epsrc.ac.uk/NGBOViewGrant.aspx?GrantRef=EP/M015521/1
Description (containing objectives, potential outcomes)	This project introduces a simple and low-cost mapping method for index keying based multicarrier systems in dispersive channels. The key concept involves a special index mapping function named MCIK (multicarrier index keying). At every transmission, only a few random sub-carriers are active for high energy-efficiency and, simultaneously, index of the active/inactive sub-carriers helps inherently to transmit extra information bits with no extra power. This MCIK concept is promising to effectively transmit big data volumes at low-power, especially on the large bandwidth and realistic dispersive channels. Our goal is to provide theoretical references and guidelines for a successful MCIK implementation that can produce significant advance; our preliminary results show 50% power savings and a potential rate of tens of gigabits per second over classical multicarrier transmission. MCIK is suitable for a power limited system modulating a large number of multicarrier. It provides a mechanism for attaining both diversity and multiplexing so that the energy efficiency and the spectral efficiency are increased. We also propose to design a linearly processed MCIK system to facilitate a low-cost data recovery process, resulting in higher spectral efficient multicarrier system. In order to effectively overcome carrier frequency offset and multiuser interference problems in the current orthogonal frequency division multiple access (OFDMA) transmissions, we propose a new multiple access technique which can allow the practical performance limits and needs for the desired performance to be easily obtained and show how MCIK features should be combined with multiuser multiple-input multiple-output systems.

Project Title	Modelling, Analysis and Design of Ultra-Dense Cellular Networks
Lead Organisation	Queen’s University of Belfast
Partners	Keysight Technologies
Funding Source	EPSRC
Funding	£96,857.00
Start / End	01/06/2017 - 31/08/2018
5G Classification Terms	HetNets, MAC / RRM
Weblink	http://gow.epsrc.ac.uk/NGBOViewGrant.aspx?GrantRef=EP/P019374/1
Description (containing objectives, potential outcomes)	This research project proposes a mathematical model to take into account the practical aspects of 5G ultra-dense networks, i.e., highly dense distribution, dynamic random topologies, and heterogeneous interference. The unique feature of the project is to augment the recent advances in mathematics, random process, and signal processing theory involved by both base stations and mobile devices in ultra-dense cellular networks for recovering the transmitted voice, data, video, etc. This allows us to integrate interference management between large and small cells along with a large number of transmit/receive antennas and higher transmission bandwidth in mm-wave frequency bands. These include the development of new theoretical framework that is informed by the limitations of a practical system not currently considered in the context of "extremely dense networks" of current cellular systems.

Project Title	Informed RF for 5G and Beyond
Lead Organisation	University of Surrey
Partners	University of Glasgow Queen’s University of Belfast Imagination Technologies ZTE * Aeroflex
Funding Source	EPSRC

Funding	£ 1,099,261
Start / End	29/04/2016 - 28/04/2019
5G Classification Terms	Radio Front-end / RF, Antenna, Baseband/ Signal processing
Weblink	http://gow.epsrc.ac.uk/NGBOViewGrant.aspx?GrantRef=EP/N020391/1
Description (containing objectives, potential outcomes)	Modern wireless communications rapidly approach the verge of the spectrum availability and new disruptive technologies are urgently needed to meet the projected capabilities and demands for efficiency and privacy of 5G communications and beyond. We will exercise an original holistic design approach to build and test novel integrated digital/RF wireless architectures exploiting the full potential of unconventional degrees of freedom and enabling dramatically increased information capacity in small-cell networks. Our cross-disciplinary studies will inform and influence future wireless technologies, help address the societal demand for 'green' and intelligent communications, and create a body of scholarship to promote the UK's unique blend of innovative engineering, free spirit of entrepreneurialism and educational rigour.

Project Title	GBSense: GHz Bandwidth Sensing from Smart Antennas to Sub-Nyquist Signal Processing
Lead Organisation	Queen Mary University of London
Partners	Electronic Media Services National Instruments Sony RWTH Aachen University *
Funding Source	EPSRC
Funding	£ 1,061,140
Start / End	01/01/2018 - 31/12/2022
5G Classification Terms	Radio Front-end / RF, Baseband/ Signal processing
Weblink	http://gow.epsrc.ac.uk/NGBOViewGrant.aspx?GrantRef=EP/R00711X/1
Description (containing objectives, potential	Data rate for exchanging mobile information among people, machines and things has been exponentially increasing over the past decade. These data rates are empirically linked to radio spectrum availability. The exorbitant auction prices, e.g., £2.3 Billion for 4G spectrum in the UK, highlights the

outcomes)	strength of the competitive market forces but also the scarcity of this precious resource. Driven by the scarcity of spectrum, the UK communications regulator (Ofcom) has made an innovative licence-exempt spectrum sharing on the ultra-high frequency (UHF) TV bands in January 2016, which is the first of its kind worldwide. These spectra of 320MHz bandwidth have enabled the transition from research on cognitive radio theory into practical applications. Furthermore, the millimetre-wave (mm-wave) spectrum on 28GHz, 39GHz, 60GHz with at least 1GHz bandwidth are being considered to be further unitised to cope with high data rate wireless applications and services demanded by users. The satellite and radar applications are co-existing in these mm-wave spectra, and thus any licence-exempt use of this spectra must first ascertain that the spectra to be used is not already in use by the so called "primary users". Therefore, sensing from several hundreds of MHz bandwidth in UHF to GHz bandwidth in mm-wave to gain a clear access to these spectra is critical, while resulting in formidable and complex challenge on the Nyquist-rate analog-to-digital sampling. This fellowship project proposes a new approach to design GHz bandwidth sensing (GBSense) systems to overcome the bottleneck of Nyquist-rate sampling by developing sub-Nyquist sampling algorithms and repurposing the existing expertise of smart antennas and reconfigurable transmission lines. The GBSense offers new creative and implementable possibilities over a framework of real-time experimental platform without requiring Nyquist-rate sampling. The GBSense gives users access to a flexible hardware platform and application software that enables real-time over the air GHz bandwidth signal sensing, analysis and communication at both sub-6GHz and mm-wave frequency bands. It will also interface with a low-cost computing unit, e.g., Raspberry PI, where sub-Nyquist algorithms are hosted, for enabling better human-computer interaction and advance the current knowledge in sub-Nyquist sampling theory and bring a new set of challenges to both software and hardware engineers. Results will be disseminated to both software and hardware academic researchers, industry and the public through workshops, change-led competitions, open-source plans and outreach activities.

Project Title	EARL: SDN enabled measurement for all
Lead Organisation	Queen Mary University of London
Partners	University of Cambridge CORSA Geant London Internet Xchange Cisco Energy Services Network
Funding	EPSRC

Source	
Funding	£ 2,024,684
Start / End	01/01/2018 - 31/12/2020
5G Classification Terms	SDN, Routing, Qos/QoE
Weblink	http://gow.epsrc.ac.uk/NGBOViewGrant.aspx?GrantRef=EP/P025374/1
Description (containing objectives, potential outcomes)	Internet eXchange Points (IXPs) have become a critical element of the Internet, as they provide the physical locations where networks interconnect and exchange traffic. IXPs carry huge traffic volumes, reduce interconnection costs, and hence make national Internet access affordable. Despite the growth of these infrastructures, the rapid evolution of the Internet poses new challenges. Reacting as soon as possible to the highly dynamic Internet environment has always been the first priority for Network Operators. Unfortunately, state-of-the-art techniques are extremely limited. Networks use the Border Gateway Protocol (BGP) to inform each other of which destinations are reachable. Accordingly, network operators (ab)use BGP Traffic Engineering (TE) to tweak traffic paths. TE is a network-management tool allowing a network to adapt events ranging from a change in customer location to mitigating dramatically large traffic outbursts of a malicious Distributed Denial of Service (DDoS) attack. However, BGP-TE lacks programmability and dynamism: once BGP preferences are set up, they cannot react in real-time to network events. With a high-fidelity measurement-focused approach, a network could implement more sophisticated traffic management techniques. For example, any network connected through an IXP must implement ingress traffic filtering to avoid receiving undesirable traffic (e.g., DDoS attacks or resulting from misconfigurations). However, correctly controlling ingress filters is complex. Thus, most IXP customers unrealistically expect the organisations originating the traffic to manage any problem. TE limitations result from the inability of current Internet monitoring techniques to cope with the wide range of granularities of network events. While control plane related events (those concerned with the selection of paths/routes, such as BGP updates) happen at a time scale of minutes, data plane events (packet processing) occur at time-scales of micro-seconds. While control plane monitoring is relatively easy, data plane observability is poor, relies on expensive equipment, and does not scale. EARL addresses this imbalance between the ability to observe control and data plane, and the consequent limits on the detection and reaction to network events. EARL is a novel integration of monitoring mechanisms and reactive network management. EARL enables a prompt reaction to network events with its Software Defined Networking (SDN) approach. Because of the IXP's central role on the Internet and the critical nature at the national

	level, we believe that they are the ideal place to explore EARL's ideas. We will demonstrate how measurement-assisted network management permits new Internet-wide services and, enables the provision of services hitherto considered impossible or too costly to deploy. Our goal for the EARL project is to pioneer SDN enabled measurement-based network management to enhance the Internet infrastructure. This will lead to relevant tools and data for the larger researcher and practitioner communities. To this aim, we will create a new research instrument, EARLnet: an operational, research-centred, Autonomous System (AS) directly connected to our partners, providing a new and unique real-world environment for the real-time monitoring of network status and SDN-oriented research. EARLnet will serve also as a test-bed to develop and evaluate novel reactive network management solutions. The EARL project has the potential to revolutionise current Internet network management through new fine-grained and reactive TE policies. EARL will not only create new mechanisms, but also translate the blind, legacy BGP-based, TE into measurement-assisted SDN techniques. Furthermore, through our partner institution, the Cambridge Cloud Cybercrime Centre (CCCC), EARLnet will provide valuable data to a large community of researchers and practitioners.

Project Title	Green Heterogeneous Networks
Lead Organisation	Manchester University
Partners	N/A
Funding Source	EPSRC
Funding	£ 624,273
Start / End	01/02/2013 - 30/06/2016
5G Classification Terms	HetNets, Energy Efficiency, MAC / RRM
Weblink	http://gow.epsrc.ac.uk/NGBOViewGrant.aspx?GrantRef=EP/J021768/1
Description (containing objectives, potential outcomes)	In this project, both goals on high energy and spectral efficiency will be targeted jointly. In particular, we will develop innovative techniques to provide radical improvement, instead of incremental enhancement. Adaptive network topology that can optimise these factors will be devised. Smart interference management and exploitation techniques will be developed to exploit the potential of HetNet. Network MIMO, cognitive radio, and 3 dimensional beamforming techniques will also be developed to achieve a green HetNet that is suitable for the future

Project Title	UPFRONT: Unlocking potentials of MIMO full-duplex radios for heterogeneous networks
Lead Organisation	UCL
Partners	China Mobile * InterDigital University of Essex Loughborough University
Funding Source	EPSRC
Funding	£ 918,238
Start / End	01/02/2016 - 31/01/2019
5G Classification Terms	HetNets, Baseband/ Signal processing, Massive / MU-MIMO, Radio Front-end / RF, Antenna
Weblink	http://gow.epsrc.ac.uk/NGBOViewGrant.aspx?GrantRef=EP/N008219/1 http://gow.epsrc.ac.uk/NGBOViewGrant.aspx?GrantRef=EP/N007840/1
Description (containing objectives, potential outcomes)	This project will develop multi-antenna full-duplex technology to achieve highly efficient spectrum usage in HetNets (heterogeneous networks). Full-duplex radios are much more than just doubling the capacity as perceived in current literature. More explicitly speaking, we believe that it is making communication technologies impossible become possible. The implications of full-duplex communications are transformative. Full duplex, which permits simultaneous transmission and reception, motivates a fundamental rethinking of the ways wireless networks are designed and optimised. However, the fact that the power of the transmitting signal is so much larger (over 100 dB) than that of the receiving signal has fuelled the belief that it is impossible to separate them on a single channel. Recently, this picture has begun to change, following the pioneering work by Choi et al. from Stanford University who demonstrated a working full-duplex radio on a single channel. We envisage that full-duplexing can transform the operations of wireless networks and is expected to have massive benefits in HetNets. HetNets are widely regarded as one key wireless technology for the provision of future wireless communications (including 5G) by complex interoperation between macrocells and small cells. The enormous interest for HetNets is due to their capability of providing high regional capacities and flexible coverage, and more importantly their low infrastructure costs. In HetNets, a mosaic of wireless coverage is obtained by a variety of wireless coverage zones from macrocell to small cell such as, pico- and femtocell. Of increasing interest to mobile operators are the customers' installed femtocells that can greatly improve indoor coverage but share the same

	frequency band as the macrocells. There is a huge scope of research in resource allocation and physical-layer design and optimisation in HetNets. This project will exploit the full potential of MIMO full-duplexing in HetNets by designing a holistic solution that interconnects antenna design, physical-layer signal processing, and network resource allocation to address the inherent challenges of full-duplexing and realise its massive end-to-end benefits. To achieve this goal, UPFRONT first proposes new antenna design specially for wideband MIMO full-duplexing, which is substantially more challenging than the existing narrowband single-antenna case. Next we leverage the powerful MIMO signal processing to handle the overlooked intercell interference and new interference introduced by the full-duplex operation, which are critical to deliver the end-to-end benefits of full-duplex HetNets but were not well studied before. Furthermore, UPFRONT will explore the unexplored full-duplexing opportunities to address the networking-wide resource allocation challenges associated with the adoption of full-duplexing small cells under the greater macrocell structure sharing the same mobile spectrum. The outcomes of UPFRONT will elucidate the importance of a holistic approach to full-duplexing design and have impact in fundamental and practical research of future wireless networks.

Project Title	SONNET: Self-Organisation towards reduced cost and energy per bit for future Emerging radio Technologies
Lead Organisation	GREENSPHERE UNIPESSOAL LDA *
Partners	PANEPISTIMIO PATRON * LONDON SOUTH BANK UNIVERSITY LBG SIGINT SOLUTIONS LTD *
Funding Source	H2020
Funding	€ 886,500
Start / End	01/01/2017 - 31/12/2020
5G Classification Terms	Network Automation, MEC (Mobile Edge Computing), SDN
Weblink	https://cordis.europa.eu/project/rcn/206391_en.html
Description (containing objectives, potential outcomes)	A revelation in today´s mobile is networks is SON (Self-Organizing technology) technology, which is seen as a playing pivotal role towards reducing the management costs of networks. In legacy networks, still many network elements and associated parameters are manually configured. The associated operations costs are significant. Specialized expertise must be maintained to tune these network parameters, and the existing manual process is time-consuming and potentially error-prone. In addition, this manual tuning process inherently results in

	comparatively long delays in updating values in response to the often rapidly changing network topologies and operating conditions, resulting in sub-optimal network performance. SON is capable of collecting information from the network, so as to perform self-configuration, self-optimization, self-healing and etc, so as to reduce the operation cost through less human involvement, and to optimize the service quality through robust and prompt network optimization. In this proposal, we aim to drive further cost savings in the way networks are managed today by amplifying further the coverage zone of SON within the network. We believe that key technologies such as network sharing and Coordinated Multipoint (CoMP) can benefit from SON technology solutions. We will consider a complex context-aware heterogeneous network that is slowly becoming a 5G reality, and investigate the notion of SON CoMP and SO network sharing, as key technologies to reduce cost and energy per bit in legacy and future emerging mobile technologies.

Project Title	Wide Smart Safe, Robust and Resilient Smart Cities Application Using Fog Computing (WATCH)
Lead Organisation	Future Intelligence Ltd
Partners	London South Bank University
Funding Source	Innovate UK
Funding	£244,621
Start / End	11/2017 - 10/2020
5G Classification Terms	MEC (Mobile Edge Computing), SDN, NFV
Weblink	http://gtr.rcuk.ac.uk/projects?ref=103845
Description (containing objectives, potential outcomes)	The aim of the WATCH project is to distribute processing to the network edge as much as possible exploiting a new type of unified telecommunication and micro-datacentre nodes able to jointly provide networking, local processing and storage resources for the support of novel applications across users with heterogeneous capabilities. The WATCH platform brings a collaborative environment to a variety of sources and devices in a smart city domain. This will be accomplished by utilising novel technologies such as SDN and NFV to facilitate the creation of "islands" of interconnected devices, which in turn form Fogs (lightweight cloud computing at the edge) to abstract resources into a unified pool. Resources on the pool will be utilised to carry out Computing, Caching and Communication (3C) resources, services/tasks and deploy them close to the end user, while at the same time use the enhanced cloud resources. WATCH objective is to improve the provisioning of smart surveillance (object detection, object

	racking, and face or text recognition) using edge computing from different types of cameras (for example, body-worn cameras, Smartphone cameras, city cameras and car recorders), IoT devices and vehicles, generating media analytics. Future Intelligence Ltd, leading SME, is already providing solutions for smart city and smart lighting and markets. This project will expand its solution portfolio with new capabilities and new featured products and services. On the other hand, London Southbank University will expand its academic leadership in advanced cloud infrastructures area.

Project Title	SYNC: Synergistic Network Policy Management for Cloud Data Centres
Lead Organisation	Liverpool John Moores University
Partners	University of Glasgow BrightOffice
Funding Source	EPSRC
Funding	£ 100,786
Start / End	01/02/2017 - 31/03/2017
5G Classification Terms	SDN, NFV, Network Automation
Weblink	http://gow.epsrc.ac.uk/NGBOViewGrant.aspx?GrantRef=EP/P004407/1
Description (containing objectives, potential outcomes)	All computer networks, including cloud data centre networks, are governed by high-level policies derived from network-wide requirements, such as "file servers should only be accessible by internal IP (Internet Protocol) addresses". Upon deployment, an individual policy is realised as a composition (or chain) of network packets processing rules that will be placed in a specified sequence of network function boxes within the network. Traditionally, implementing network policy is an error-prone manual configuration process. Emerging technologies such as Software-Defined Networking (SDN) and Network Function Virtualisation (NFV) have largely eliminated the need of manual configuration through software automation. Nevertheless, the use of SDN and NFV have resulted in greater number of independent network nodes that dynamically generate and implement policy rules respectively, making correct policy implementation a hard problem to solve. Worse still, this problem is amplified by the dynamic virtual machine (VM) consolidation in cloud data centre since migrating VMs means that the "specified sequence" must also be updated across the network. Imperfect policy implementation will lead to policy violation that attributes to 78% of data centre downtime, which costs $5,600(£3,758) per minute.

	This demonstrates the necessity of synergistic placement of network policy rules and application VMs, as captured in the SYNC project hypothesis: Infrastructural configuration and utilisation as well as application performance of cloud data centres is largely dictated by the placement of network policy rules and application virtual machines. This is in contrast to the existing approaches which either only consider static rules placement, or perform dynamic placement without taking into account the application VMs. In this project, we propose the development of SYNC, a synergistic network policy management framework that will lever synergy amongst a) policy rules, b) applications and c underlying temporal network state for achieving network-wide performance optimisation. In order to realise SYNC, the following research and development tasks will take place: i). The high-level network policy expressions will be decomposed into minimum set of network-wide consistent chains of rules, which are in turn implemented in network function boxes at different network locations, e.g. middleboxes, network switches, and end hosts. ii). The underlying network state will be exploited to (re)arrange application virtual machines and rules so that the network-wide impact of pairwise traffic patterns is minimised. The key challenge in this innovation will be the scale of the underlying infrastructure, which can have up to a million VMs and millions of rules. We will construct appropriate models and efficient algorithms, combined with SDN and NFV overcome this challenge. We intend to publish research outcome in prestigious journals and conferences, provide open-access to the research data, and commercialise our intellectual property.

Project Title	ULTRAWAVE: Ultra capacity wireless layer beyond 100 GHz based on millimetre wave Traveling Wave Tubes
Lead Organisation	Lancaster University
Partners	FIBERNOVA SYSTEMS SL * FORSCHUNGSVERBUND BERLIN EV * JOHANN WOLFGANG * GOETHE-UNIVERSITATFRANKFURT AM MAIN * HF SYSTEMS ENGINEERING GMBH & CO KG * OMMIC SAS * UNIVERSITAT POLITECNICA DE VALENCIA * UNIVERSITA DEGLI STUDI DI ROMA TORVERGATA *
Funding Source	H2020
Funding	€ 2,971,366.25

Start / End	01/09/2017 - 31/08/2020
5G Classification Terms	mmWAVE, Radio Front-end / RF
Weblink	http://ultrawave2020.eu/
Description (containing objectives, potential outcomes)	For the first time, smartphones and tablets data usage exceeds desktops. This is a wake up call for manufacturers and operators to provide users with ubiquitous, high speed and high quality wireless coverage. The 5G cell densification is the only available route due to the constraints of sub-6GHz networks. A dense deployment of small cells requires a capillary backhaul and novel approaches to fronthaul. While the increase of data rate at small cell level has found solutions, the quest for high-density backhaul remains still unanswered. The fibre is too expensive and of difficult deployment. The wireless backhaul is the preferred solution for operators for performance, flexibility and cost. The traffic demand requires an upshift from microwave to high capacity millimetre wave backhaul, and overcome the current technology limits. ULTRAWAVE responds to the challenge of high capacity, high cell density backhaul by proposing, for the first time, the exploitation of the whole millimetre wave spectrum beyond 100 GHz. This will be used to create an ultra-capacity layer providing more than 100 Gbps per kilometre square in Point to Multi point at D-band (141 – 174.8 GHz) over 500 m radius of coverage, fed by novel G-band (300 GHz) Point to Point high capacity links with more than 600 m range. The ULTRAWAVE system is empowered by the convergence of three main technologies: vacuum electronics, solid-state electronics and photonics in a unique wireless system, with transmission power at Watt level at millimetre waves, generated by novel traveling wave tubes. The ULTRAWAVE consortium includes five top Academic institutions and three high technology SMEs from five European countries. The vast capacity, flexibility and easy deployment of the ULTRAWAVE layer will enable backhaul of hundreds of small and pico cells, no matter the density, and will open scenarios so far not conceivable for new networks paradigms and architectures aiming at a full 5G implementation.

Project Title	TWEETHER: Traveling Wave Tube based W-band Wireless Networks with High Data Rate, Distribution, Spectrum and Energy Efficiency
Lead Organisation	Lancaster University
Partners	THALES ELECTRON DEVICES SAS * BLUWAN * OMMIC SAS * HF SYSTEMS ENGINEERING GMBH & CO KG *

	JOHANN WOLFGANG * GOETHE-UNIVERSITATFRANKFURT AM MAIN * FIBERNOVA SYSTEMS SL * UNIVERSITAT POLITECNICA DE VALENCIA * INSTITUT MINES-TELECOM * ERTE-ETUDES ET REALISATIONS DE TRAVAUX * ELECTRONIQUES SAS *
Funding Source	H2020
Funding	€ 3,333,722.50
Start / End	01/01/2015 - 31/12/2017
5G Classification Terms	mmWAVE, Other, Radio Front-end / RF
Weblink	https://cordis.europa.eu/project/rcn/194233_en.html
Description (containing objectives, potential outcomes)	Never technology has penetrated so deeply and fast in society everyday life as Internet has done in the last decades and is expected to do in the future. The enormous flux of data transferred via wireless networks, increasing at exponential pace, makes today's state of the art networks soon outdated. Large parts of the society are deprived of adequate access to Internet due to the high costs, long deployment time of optical fibres and inadequate performance of wireless networks. This inequality will most likely pertain in the next years. Millimetre waves are the most promising solution to support the increasing data throughput and to be a credible fibre complement for the last miles. The TWEETHER aim is to realise the millimetre wave Point to multi Point segment to finally link fibre, and sub-6GHz distribution for a full three segment hybrid network, that is the most cost-effective architecture to reach mobile or fixed final individual client. The TWEETHER project responds to the call H2020-ICT6, to foster smart wireless network architecture for high capacity everywhere outdoor data distribution, in gigabit class, that other technologies cannot support, at low operating cost. High spectrum and energy efficient W-band (92-95GHz) technology will be developed. A powerful and compact transmission hub based on a novel traveling wave tube power amplifier with performance precluded to any other technology and an advanced chipset in a compact terminal will be realised. The TWEETHER system will be tested in a real operating environment. Integrated smart networks of backhaul for 4G and 5G small cells and of access for residential houses are the targeted market that benefits from the actual light regulation of W-band. A big company Thales Electron Devices, four SMEs, Bluwan, OMMIC, HFSE, Fibernova, and three top Universities, Lancaster, Goethe Frankfurt, Politecnica de Valencia, join their expertise to successfully tackle the formidable challenges of the TWEETHER project

Project Title	SkyBridge
Lead Organisation	Horsebridge Network Systems
Partners	University of Surrey Bentley Motors Limited RINICOM LIMITED Lancaster University
Funding Source	Innovate UK
Funding	£2,921,893
Start / End	10/2017 - 09/2019
5G Classification Terms	SDN, MEC (Mobile Edge Computing), Network Slicing, Radio Front-end / RF, Antenna, Automotive, HetNets
Weblink	http://gtr.rcuk.ac.uk/projects?ref=103882
Description (containing objectives, potential outcomes)	The SkyBridge project brings together unique & innovative organisations of SME's, Universities & an automotive OEM to form a 5G Innovation Value Chain in a collaborative development of a network connectivity solution for passenger journeys & smart cities. This solution leverages a defence sector technology from Horsebridge which allows the user to benefit from the secure, aggregated bandwidth from up to 4 mobile network operators & tailors it specifically for smart infrastructure & connected transport needs. In particular SkyBridge will be future-proofed to ensure compatibility with emerging 5G standards across secure, massive & critical IoT platforms. This novel connectivity solution allows improved & enhanced services to be provided to consumers to enrich their passenger experience & enables the provision of better services, greater flexibility with wider economic, social & environmental benefits. SkyBridge supports the UK’s drive to develop capability & technologies which will position it at the forefront of the 5G Smart & Secure Living environment.

Project Title	OFELIA: Open Flow in Europe: Linking Infrastructure and Applications
Lead Organisation	EUROPEAN CENTER FOR INFORMATION AND COMMUNICATION TECHNOLOGIES GMBH *
Partners	UNIVERSITY OF ESSEX UNIVERSITY OF BRISTOL NEC EUROPE LTD LANCASTER UNIVERSITY IMINDS * FUNDACAO DE APOIO A UNIVERSIDADE DE SAO PAULO * FUNDACAO DE APOIO UNIVERSITARIO *

	EIDGENOESSISCHE TECHNISCHE HOCHSCHULE ZUERICH * TECHNISCHE UNIVERSITAET BERLIN * DEUTSCHE TELEKOM AG * ADVA OPTICAL NETWORKING SE * CENTRE TECNOLOGIC DE TELECOMUNICACIONS DE CATALUNYA * FUNDACIO PRIVADA I2CAT, INTERNET I INNOVACIO DIGITAL A CATALUNYA * CONSORZIO NAZIONALE INTERUNIVERSITARIO PER LE TELECOMUNICAZIONI * CREATE-NET (CENTER FOR RESEARCH AND TELECOMMUNICATION EXPERIMENTATION FOR NETWORKED COMMUNITIES) * INSTITUTO DE TELECOMUNICACOES * BOARD OF TRUSTEES OF THE LELAND STANFORD JUNIOR UNIVERSITY * ADVA OPTICAL NETWORKING SP. Z.O.O *
Funding Source	FP7
Funding	€ 4,449,912
Start / End	01/09/2010 - 31/10/2013
5G Classification Terms	System Integration / Validation / Simulation, Optical Network, SDN
Weblink	https://cordis.europa.eu/project/rcn/95927_en.html
Description (containing objectives, potential outcomes)	The aim of the OFELIA project is to create a unique experimental facility that allows researchers to not only experiment 'on' a test network but to control the network itself precisely and dynamically. To achieve this, the OFELIA facility is based on OpenFlow, a currently emerging networking technology that allows to virtualize and control the network environment through secure and standardized interfaces. In a nutshell, OpenFlow enables experimenters to change the behaviour of the network as part of the experiment rather than, if at all, as part of the experiment setup. OFELIA will provide high-performance OpenFlow equipment to enable experiments at scale and to ensure that the facility is based on mature technology. Another strength of OFELIA is its concept of federated or interconnected islands. A set of five islands creates a diverse OpenFlow infrastructure that allows experimentation on multi-layer and multi-technology networks provided by the different islands. The facility will extend all the way from standard Ethernet to optical and wireless transmission and it will also include an emulation wall for scalability tests comprising thousands of nodes. The facility will grow in three phases to, on the one hand provide an early access to the facility (after 6 months already) and, on the other hand to evolve during the project lifetime, incorporating the feedback of the user community and extending its reach to other test facilities. Two open calls will be published to invite experimenters that

	bring their use cases and scenarios to the facility creating a feedback loop to extend the OFELIA facility according to the needs of the user community.

Project Title	Understanding and managing energy use in future networks
Lead Organisation	Lancaster University
Partners	University of Passau *
Funding Source	EPSRC
Funding	£ 348,901
Start / End	01/03/2011 - 30/11/2013
5G Classification Terms	Energy Efficiency
Weblink	http://gow.epsrc.ac.uk/NGBOViewGrant.aspx?GrantRef=EP/I00016X/1
Description (containing objectives, potential outcomes)	This 2 year project will leverage Lancaster University's entire computational resource network to form a 1000 host testbed for end-to-end energy consumption management options. The study will characterise current usage patterns and evaluate the opportunities presented by emerging applications and technologies for consumption reduction. The study will assess both central control options and engaging information sharing coupled with participative management decision making as means for reducing consumption. The study will propose and test an optimal combination of the two approaches. Additional outcomes will include future network sustainability forecasts, user behaviour predictions and novel consumption management strategies.

Project Title	sBGP: A hybrid SDN approach to interdomain routing
Lead Organisation	Lancaster University
Partners	N/A
Funding Source	EPSRC
Funding	N/A
Start / End	05/2016 - 03/2020
5G Classification Terms	SDN, Routing
Weblink	http://gtr.rcuk.ac.uk/projects?ref=studentship-1806136

Description (containing objectives, potential outcomes)	This is a PhD studentship This proposal presents a new network architecture which incorporates aspects of both SDN and classical BGP based architectures. It extends other SDN work in two ways: a) by adopting an existing protocol (BGP) as a new southbound protocol, and b) by implementing a 'hybrid'2 approach to SDN for routed networks at layer 3. It extends classical BGP based internet architectures by retaining the network elements (routers), and the associated control software without modification, whilst removing from those routers the responsibility for autonomously determining local forwarding policy, and collectively with other peer routers determining system-wide routing behaviour and communicating with external networks (other Autonomous Systems). In doing so it keeps the high performance and scale of current core router hardware whilst removing the dependency on core router control software to implement optimal network wide routing policy. The benefit of retaining BGP is that it provides exactly the level of control over the forwarding plane which is required for the task, and existing implementations are known to have the scaling and performance capacity to support at least the current internet demands. This proposal is based on the premise that an 'SDN like' analysis of Internet (routing) architecture is clearly applicable both from the standpoint of the SDN community - "if SDN is not applicable here, then where?", and also the Internet industry, where the principle of automating network operations ('devops') is central to most any strategies for improving Internet management, and what else is 'automating network operations, using software' than SDN by another name? The novelty of this proposal is the explicit selection of BGP as a southbound SDN protocol. Implementations of network systems based on SDN and supporting BGP externally, or as a northbound interface (or east-west interface) can be found, albeit in small number, and in most cases not even in the classical role of core Internet routing, however the consideration of BGP as a first class SDN protocol alongside OpenFlow, and the consideration of hybrid SDN solutions is a very lightly touched topic in the field of SDN research.

Project Title	A Unified Multiple Access Framework for Next Generation Mobile Networks By Removing Orthogonality (MANGO)
Lead Organisation	Heriot-Watt University
Partners	Nokia Samsung QinetiQ Mobile VCE University of Edinburgh Lancaster University
Funding Source	EPSRC

Funding	£ 940,622
Start / End	01/08/2017 - 31/07/2020
5G Classification Terms	Baseband/ Signal processing, MAC / RRM
Weblink	http://gow.epsrc.ac.uk/NGBOViewGrant.aspx?GrantRef=EP/P009670/1 http://gow.epsrc.ac.uk/NGBOViewGrant.aspx?GrantRef=EP/P009549/1 http://gow.epsrc.ac.uk/NGBOViewGrant.aspx?GrantRef=EP/P009719/1
Description (containing objectives, potential outcomes)	The design of novel radio access technologies is an important aspect in improving spectrum efficiency in a cost-effective manner for future mobile networks. Radio access technologies are typically characterised by orthogonal multiple access schemes, e.g., frequency division multiple access (FDMA), time division multiple access (TDMA), code division multiple access (CDMA), and orthogonal FDMA (OFDMA) that provide the means for multiple users to access and share the radio resources simultaneously. One of the key issues with the orthogonal multiple access (OMA) schemes, for example, OFDMA used by 3GPP-LTE, is that when some bandwidth resources, such as subcarrier channels, are allocated to users with poor channel condition, it results in lower spectrum efficiency. Motivated by the spectral inefficiency of OMA techniques, non-orthogonal multiple access (NOMA) has been recognised recently as a promising multiple access technique to significantly enhance the spectral efficiency and is envisioned to be a key component of the next generation mobile networks. The dominant NOMA schemes are grouped in two categories: power-domain or code-domain NOMA. In power-domain NOMA, users are allocated different power levels according to their channel conditions to obtain the maximum gain in system performance whereas in code-domain NOMA, different users are assigned different codes, and are then multiplexed over the same time-frequency resources. However, NOMA techniques still involve several critical challenges such as lack of insightful understanding of the performance limits of NOMA and a large gap in the performance evaluation of NOMA transceivers under single-/multiple antennas, single-/multi-cell cases, which makes their immediate deployment prohibitive. This visionary project tackles the issue of NOMA techniques' deployment in next generation mobile networks by establishing a unified theoretical framework and developing sophisticated digital signal processing algorithms to realise the concept of NOMA in single-/multiple antenna, single-/multi-cell scenarios. The novelty of this project lies in a) information theoretical analysis with practical constraints, b) less-computationally complex transceiver design for power-domain and code-domain NOMA c) joint precoding design for single- and multi-cell NOMA networks, d) NOMA applications in cognitive radio and IoT systems and e) system level performance evaluations in next generation mobile network scenarios.

Project Title	Massive MIMO for future Wireless Communication Networks
Lead Organisation	Lancaster University
Partners	University of Edinburgh Newcastle University Mobile VCE
Funding Source	EPSRC
Funding	£ 483,431
Start / End	13/02/2015 - 12/11/2018
5G Classification Terms	Massive / MU-MIMO, Baseband/ Signal processing, Propagation / Channel Modelling
Weblink	http://gow.epsrc.ac.uk/NGBOViewGrant.aspx?GrantRef=EP/L025272/1 http://gow.epsrc.ac.uk/NGBOViewGrant.aspx?GrantRef=EP/L025299/1
Description (containing objectives, potential outcomes)	The spectrum crunch is a global phenomenon, where wireless networks constrained by scarce spectrum resource cannot keep pace with the explosion in mobile broadband use, particularly at a time when smartphones and tablets are becoming even more prevalent and heavily used. Every new opportunity has to be maximally exploited to cope with this spectrum deficit and meet the demands of explosive broadband usage by pushing more data through existing spectrum. Massive multiple-input multiple-output (MIMO), an advanced antenna technology only developed in 2010 offers one such opportunity. Massive MIMO enables a sparse infrastructure network, whereby a single base station (BS) is powerful enough to eliminate inter-cell interference through highly directional beamforming, and hence avoid the need for any cell-to-cell coordination. Initial work, particularly the experiments in have demonstrated the feasibility of massive MIMO. However, there is still lack of insightful understanding of the fundamental limits of massive MIMO, and also there is a large gap in the performance evaluation of massive MIMO under ideal and non-ideal practical conditions. The aim of this project is to establish a unified theoretical framework for the fundamental limits of massive MIMO with various practical constraints, and develop sophisticated signal processing algorithms to realize the concept of massive MIMO in realistic environments. The novelty of this project lies in the fact that advanced mathematical tools, such as random matrix theory and stochastic geometry, will be used to capture the dynamic nature of multi-user wireless channels. Sophisticated signal processing methods, such as game theoretic algorithms and compressed sensing, will be applied to massive MIMO in order to combat the practical constraints, such as frequency selective channel fading and limited channel feedback.

Project Title	Robustness-as-evolvability: building a dynamic control plane with Software

	Defined Networking
Lead Organisation	Lancaster University
Partners	University of Edinburgh University of Birmingham Samsung Princeton University* InMon Corp Fortinet VMWare Juniper Brocade
Funding Source	EPSRC
Funding	£ 345,908
Start / End	01/06/2015 - 31/12/2017
5G Classification Terms	SDN, Security, Network Automation
Weblink	http://gow.epsrc.ac.uk/NGBOViewGrant.aspx?GrantRef=EP/L022796/1
Description (containing objectives, potential outcomes)	Highly available information networks are an increasingly essential component of the modern society. Targeted attacks are a key threat to the availability of these networks. These attacks exploit weak components in network infrastructure and attack them, triggering side-effects that harm the ultimate victim. Targeted attacks are carried out using highly distributed attacker networks called botnets comprising between thousands and hundreds of thousands of compromised computers. A key feature is that botnets are programmable allowing the attacker to adapt to evolve and adapt to defences developed by infrastructure providers. However current network infrastructure is largely static and hence cannot adapt to a fast evolving attacker. To design effective responses, a programmable network infrastructure enabling large-scale cooperation is necessary. Our research will create a new form of secure network infrastructure which detects targeted attacks on itself. It then automatically restructures the infrastructure to maximise attack resilience. Finally, it self-verifies whether global properties of safety and correctness can be assured even though each part of the infrastructure only has a local view of the world. Our research will examine techniques to collect and merge inferences across distributed vantage points within a network whilst minimising risks to user privacy from data-aggregation using novel privacy techniques. We make a start on addressing the risks introduced by programmability itself, by developing smart assurance techniques that can verify evidence of

	good intention before the infrastructure is reprogrammed. We set three fundamental design objectives for our design: (1) Automated and seamless restructuring of network infrastructure to withstand attacks aimed at strategic targets on the infrastructure. (2) A measurement system that allows dynamic allocation of resources and fine control over the manner, location, frequency, and intensity of data collected at each monitoring location on the infrastructure. (3) Assurance of safety and compliance to sound principles of structural resilience when infrastructure is reprogrammed. Our aim is to develop future network defences based on a smart and evolving network infrastructure.

Project Title	TERALINKS: Terahertz high power links using photonic devices, tube amplifiers, and smart antennas
Lead Organisation	Lancaster University
Partners	Queen Mary University of London UC Davis *
Funding Source	EPSRC
Funding	£ 400,654
Start / End	01/04/2017 - 31/03/2019
5G Classification Terms	Radio Front-end / RF, mmWAVE, Antenna
Weblink	http://gow.epsrc.ac.uk/NGBOViewGrant.aspx?GrantRef=EP/P015883/1 http://gow.epsrc.ac.uk/NGBOViewGrant.aspx?GrantRef=EP/P016421/1
Description (containing objectives, potential outcomes)	The TERALINKS project is dedicated to the demonstration of a real-time THz communication system, with the 200-300 GHz bandwidth, in an operational environment. The TERALINKS consortium aims to integrate three key enabling technologies and demonstrate the state of the art system with industrial relevance: THz sources (photonics- based for bandwidth and core network compatibility), THz power generation using travelling wave tubes as one of the most promising high power sources at frequencies of interest, and advanced THz antennas. The TERALINKS consortium consists of key European institutes with notable but complementary expertise in every key building block of novel THz communication systems, and all consortium

	members have established considerable experiences in developing THz communication components and the system using technologies than span from photonics, to high frequency electronics. Our vision is to take fundamental research from individual university labs to a point where it is can revolutionise future mobile communications, with a manifold return for Europe, in innovation and exploitation. The project duration is proposed for 24 months.

Project Title	NG-CDI: Next Generation Converged Digital Infrastructure
Lead Organisation	Lancaster University
Partners	Bristol University University of Cambridge University of Surrey BT
Funding Source	EPSRC
Funding	£ 2,561,398
Start / End	01/11/2017 - 31/10/2022
5G Classification Terms	Network Automation, SDN, NFV
Weblink	http://gow.epsrc.ac.uk/NGBOViewGrant.aspx?GrantRef=EP/R004935/1
Description (containing objectives, potential outcomes)	This programme will forge the research required to underpin the next generation converged digital infrastructure for BT, creating a radically new technology architecture for autonomous operation of future networks and services. Digital infrastructure networks of the future will be highly reliable and resilient to disruptions through autonomous operations and will be able to cope with increasing demands on its capacity and types of services. These networks will be equipped with programmable and virtualised network functions that can be flexibly placed at specific network locations. New and unpredicted services will be capable of being supported without the need to make costly changes to the infrastructure at the physical level. The physical nodes of the infrastructure network will be represented digitally by a 'digital twin' or 'software agent' which will make them "autonomic" - i.e., the capability to perceive its state and environment, understand and predict its behaviour, and react to disruptions and opportunities autonomously with an aim to enhance customer experience. The network will be able to detect and predict possible disruptions, analyse the risk to service provision, make autonomous decisions regarding the (re)deployment of functions to least risky network locations and arrange remedial actions such as repair or replacement of risk-prone nodes. This will lead to new services, improved resilience of the network, better customer experiences and greater operational efficiency ensuring that the

	UK remains a leading digital economy. In order to realise this vision, the research carried out in this programme is structured around 5 challenges: Research Challenge 1: Agile Converged Infrastructure Systems Architecture. The fundamental question addressed here is "How to build an agile digital infrastructure that is amenable to autonomous operations?" This will be achieved through developments in new technologies such as MicroNFV and SDN. Research Challenge 2: Future Networks Operations and Services. The fundamental question addressed here is "How to ensure service reliability of the agile autonomic digital infrastructure?" This will be achieved by developing an automated service ecosystem capable of placing virtualised network functions at specific network locations. Research Challenge 3: Autonomic Knowledge Framework. This challenge addresses the question "How to enable autonomous operational ability for the digital infrastructure?" This is tackled by a multi-agent system architecture and through creating data sources that are intelligent. Research Challenge 4: Autonomous Diagnostics and Response. This challenge addresses the question "How can the digital infrastructure respond to disruptions autonomously?" This will be answered by developing novel automated change detection and statistical learning techniques. Research Challenge 5: Future Organisational Dynamics. The question addressed here is "How can the organisation exploit the autonomic agile capabilities of the digital infrastructure?" This is addressed by developing decision-support algorithms for risk-based function redeployment and predictive asset management.

Project Title	Communications Signal Processing Based Solutions for Massive Machine-to-Machine Networks (M3NETs)
Lead Organisation	University of Leicester
Partners	Loughborough University Queen Mary University of London AWTG Mobile VCE BT
Funding Source	EPSRC
Funding	£ 937,354
Start / End	01/10/2017 - 25/02/2021
5G Classification Terms	MAC / RRM, IoT - Smart Cities, Baseband/ Signal processing, D2D, System Integration / Validation / Simulation
Weblink	http://gow.epsrc.ac.uk/NGBOViewGrant.aspx?GrantRef=EP/R006385/1 http://gow.epsrc.ac.uk/NGBOViewGrant.aspx?GrantRef=EP/R006466/1 http://gow.epsrc.ac.uk/NGBOViewGrant.aspx?GrantRef=EP/R006377/1

Description (containing objectives, potential outcomes)	Future wireless networks should have the capability of serving a wide range of personal wireless devices and appliances with stringent end-to-end delay requirements. These appliances will be equipped with the capabilities to sense various real time events and be able to self-configure via network connections, thereby paving the way for many emerging applications including e-health, intelligent transportation and smart cities. The most important enabling technologies for these applications is seamless machine-to-machine (M2M) wireless communications, which is the key to sustaining large-scale massive interconnections between things. The number of M2M devices has been growing exponentially, and is expected to reach up to 50 billion by 2020. This trend in the market growth for both M2M devices and M2M connectivity segments will further accelerate in the future. Along with it, by 2020, M2M connections will generate 6.7 percent of total mobile traffic-up from 2.7 percent in 2015. As such, M2M communications is envisioned as one of the five disruptive technology directions for fifth generation (5G) wireless networks and beyond. Despite the importance of machine-type communications, there are many critical challenges that need to be addressed in terms of network congestion and overload due to presence of massive M2M devices with heterogeneous traffic patterns, unprecedented level of inter and intra interference among M2M and human-to-human (H2M) communications, complex resource management due to irregular traffic patterns and energy constraints. The focus of this project is on tackling these critical challenges, by advancing aspects of communications signal processing, stochastic geometry, convex optimizations and game theory. In particular, we will contribute in terms of characterising heterogeneous traffic patterns associated with massive M2M communications, development of distributed random access channel protocols, proposal of convex and game theoretic resource allocation methods and design of energy harvesting constraint based cross-layer optimisation algorithms and protocols. All the concepts and algorithms developed will be integrated and the radio link layer performance will be assessed using a simulation reference system based on LTE-Advanced standards and its evolution towards 5G. Industrial partners will be engaged throughout the project to ensure industrial relevance of our work.

Project Title	SENSE: Scalable Full Duplex Dense Wireless Networks
Lead Organisation	King’s College London
Partners	Bristol University Queen Mary University of London Intel uBLOX Thales Toshiba Rohde Schwarz

	Vodafone
Funding Source	EPSRC
Funding	£ 1,1174,303
Start / End	23/01/2017 - 22/01/2020
5G Classification Terms	Baseband/ Signal processing, MAC / RRM, Routing
Weblink	http://gow.epsrc.ac.uk/NGBOViewGrant.aspx?GrantRef=EP/P003486/1 http://gow.epsrc.ac.uk/NGBOViewGrant.aspx?GrantRef=EP/P002978/1
Description (containing objectives, potential outcomes)	In response to the growing demands for delivery of content-rich and delay-sensitive services, network architectures for 5th generation and beyond wireless communication systems are becoming more and more dense. This illustrated through the ever increasing deployment of small cell networks as well as machine-to-machine (M2M) communications. This trend, whilst improving network capacity, will still necessitate reuse of available resources such as frequency spectrum within smaller areas by larger number of nodes/cells, which in turn would adversely affect the quality of service. On the other hand, by allowing simultaneous transmission and reception in the same frequency band, In-band Full-Duplex Communication (IFDC) technology potentially enhances the spectral efficiency of a single point-to-point (P2P) channel by 100% over the conventional half-duplex communication. IFDC also enables the nodes, e.g. in P2P scenarios, to receive channel feedback or sense other channels whilst transmitting data, which shortens the latency compared to conventional half duplex communication with time-division-duplexing. Moreover, using full duplex relay nodes in multi-hop scenarios can potentially reduce the end-to-end latency by enabling simultaneous receiving and relaying. Practical implementation of this technology requires rigorous interference cancellation methods at each node to suppress the strong self-interference imposed on the receiver by the transmitter of the same node. The major bulk of research on IFDC has focused on self-interference cancellation (SIC), and the respective state-of-the-art technology can achieve a high level of SIC at full duplex terminals; hence the IFDC technology has become closer to commercial deployment by industry. Deploying IFDC in realistic dense settings entails new range of technical challenges, and opportunities alike. IFDC can yield substantially greater network throughputs and delay reductions over half duplex networking by deploying the technology in denser networks. However, attaining such gains demands for efficient scalable resource allocation and multi-node interference control methods. This great potential of 'full-duplex dense networks' in 'scalable service provisioning' has not been addressed to date by the research community in sufficient depth.

	At physical-layer, new resource allocation challenges arise in IFDC networks; for instance, in the design of concurrent channel sensing and data transmission, and in adapting transmit power of the nodes to their variable self-interference. Also, using IFDC in dense scenarios will affect design of the protocols in the higher layers; for instance IFDC would entail greater chance of packet collisions and multi-node interference, which demands for new medium access control (MAC) protocols suited to the emerging dense full duplex networks. Furthermore, IFDC will enable full duplex relaying in multi-hop communication, hence requires new Forwarding-layer/Network-layer protocols to deal with the new full-duplex forwarding paradigms. For conventional half duplex scenarios it is known that network throughput and quality of services can be improved through cross-layer methods, particularly with co-design of physical and MAC layers or MAC and Network/Forwarding layers. In fact for optimal scalability of heterogeneous services in full duplex dense networks, cross-layer approaches are inevitable. This project aims to propose systematic design of resource allocation and interference suppression techniques and algorithms at physical, MAC and Forwarding layers in order to enable substantial throughput gain and delay reduction by deploying full-duplex communication in dense wireless networks. These new methods will pave the way for deploying scalable service provisioning in the emerging dense wireless networks.

Project Title	Massive MIMO wireless networks: Theory and methods
Lead Organisation	UCL
Partners	Three UK Loughborough University Queen Mary University of London Thales Mobile VCE King's College London Newcastle University
Funding Source	EPSRC
Funding	£ 664,4145
Start / End	24/04/2015 - 23/04/2018
5G Classification Terms	Massive / MU-MIMO, Propagation / Channel Modelling, Baseband/ Signal processing
Weblink	http://gow.epsrc.ac.uk/NGBOViewGrant.aspx?GrantRef=EP/M015475/1 http://gow.epsrc.ac.uk/NGBOViewGrant.aspx?GrantRef=EP/M016005/1

	http://gow.epsrc.ac.uk/NGBOViewGrant.aspx?GrantRef=EP/M016145/2
Description (containing objectives, potential outcomes)	Spectrum is a precious but scarce natural resource. In the UK, Ofcom will free up the analogue TV spectrum at 800MHz (together with the available 2.6GHz band) for 4G, which has already raised £2.34 billion for the national purse. According to Ofcom, the amount of data Britons consume on the move each month has already hit 20 million gigabytes, mainly due to users' engagement of video, TV and films while on the move. It is also a common understanding for the mobile operators that by 2020 a 1000 times increase in the system capacity will be needed to avoid mobile networks grinding to a halt. Maximising spectral efficiency, which is limited by interference and fading for wireless networks including 4G, is therefore a major issue. An emerging idea, which is championed by Alcatel-Lucent and has already received serious consideration by vendors and operators is that of a massive MIMO antenna system. This technology has the potential to unlock the issue of spectrum scarcity and to enhance spectrum usage tremendously by enabling simultaneous access of tens or hundreds of terminals in the same time-frequency resource. In order for massive MIMO technology to attain its utmost potential, it is important that various challenges in terms of channel estimation and acquisition due to pilot contamination, fast spatial-temporal variations in signal power and autonomous resource allocation, in particular in the presence of simultaneous access of a large number of users need to be addressed. The focus of this project is on tackling these fundamental challenges, by advancing aspects of information theory, estimation theory and network optimisations. In particular, we will contribute in terms of modelling massive MIMO channels underpinned by heterogeneous correlation structures; performing information theoretic analysis in terms of random matrix theory through shrinkage estimators; robust precoder design for massive MIMO in the presence of channel estimation errors; developing novel channel estimation technique in the presence of severe pilot contamination; and proposing and analysing game theoretic algorithms for autonomous resource allocation and pilot assignments. All the concepts and algorithms developed will be integrated and the radio link layer performance will be assessed using a simulation reference system based on LTE-Advanced standards and its evolution towards 5G. Industrial partners will be engaged throughout the project to ensure industrial relevance of our work.

Project Title	CommNet-II: UK Research Strategy Community Organisation in Communications, Mobile Computing and Networking within the EPSRC ICT Portfolio
Lead Organisation	Sheffield University
Partners	NEC Lancaster University University of Surrey University of East Anglia Bristol University King’s College London

Funding Source	EPSRC
Funding	£ 236,142
Start / End	28/10/2015 - 27/10/2018
5G Classification Terms	Other
Weblink	https://www.commnet.ac.uk/
Description (containing objectives, potential outcomes)	CommNet2 will bring together UK academics from the broad ICT space in order to derive and deliver a coherent national research programme that makes a real impact on the world stage. The increasingly complex multi-disciplinary engineering challenges associated with 5G and beyond, edge and core networking infrastructure, the Internet of Things (IOT), Data Analytics, Federated Cloud Fabric and the Tactile Internet necessitates a cross-disciplinary approach to research spanning knowledge sets from the underpinning fundamentals of materials through devices and subsystems to integrated systems, architectures and protocols. CommNet2 seeks to consolidate such an effort at the UK national scale to address the new challenges faced by society. Many of these challenges map against evolving EPSRC priorities for the IoT, Big Data Analytics, Robotics and Autonomous Systems, Towards an Integrated Information Infrastructure, Complex Systems and Cognitive Computing, Security & Privacy and the emerging Research and Innovation Internet Environment. Mapped against the EPSRC ICT Theme Priorities, a three year programme of activities is proposed that include networking and training events; international research-horizon scanning; best practice challenge workshops and conferences; and opportunities for early career researchers. The overarching aim of CommNet2 is to develop a robust framework in order to streamline and facilitate the academic innovation process towards delivering coherent and ground-breaking research directions shared by the communications and computer science disciplines to tackle 21st century ICT challenges. As a community driven response, the network will bring together academics from the electrical engineering, electronics, communications, networking, mathematics and computer science disciplines to achieve enhanced coordination of these researchers. Specifically, the network will create a vehicle enabling coordinated discussions and formulations of future research bids, activities and world-leading publications that establish internationally leading research activities. CommNet2 will benefit the UK by: mobilising the UK's academic and industrial communities in the ICT space to undertake world-leading research programmes; providing younger ICT researchers with training and networking opportunities to develop into tomorrow's leaders; and building a strong, vibrant and cohesive community across the communications and computer science disciplines. The UK has long had global strength in the ICT arena. From pioneering mobile operators through to a rich heritage of start-ups and consultancies we have been at the

	forefront of wireless and wireline communications for decades. This reputation has led to innovation, continued inward investment from major global players and the establishment of important clusters around the UK, such as Cambridge, Shoreditch, Bristol and Northern Ireland, the Surrey 5GIC as well as the successful phases of the m-VCE. The advent of 5G, superfast broadband, the IoT, cloud computing and the Tactile Internet provides an opportunity to reinforce the UK's strengths in ICT. Through CommNet2, the academic community, by working closely with the relevant industry and organisations, will catalyse a step-change in ICT research for the benefit of society.

Project Title	Enabling High-Speed Microwave and Millimetre Wave Links (MiMiWaveS)
Lead Organisation	Queen Mary University of London
Partners	BT Mobile VCE King's College London
Funding Source	EPSRC
Funding	£ 541,797
Start / End	01/09/2016 - 31/08/2019
5G Classification Terms	Massive / MU-MIMO, mmWAVE, Baseband/ Signal processing, HetNets, Media (AR/VR)
Weblink	http://gow.epsrc.ac.uk/NGBOViewGrant.aspx?GrantRef=EP/N029666/1
Description (containing objectives, potential outcomes)	Wireless communications has been shaping the planet in an unprecedented way as we live in an increasingly connected, automated, and globalised society of smart environments where the physical world is connected with the information world. Looking 10-20 years ahead, multi-gigabit wireless communications will play an even more prominent role in the evolution and development of our unwired networked society. This project is proposed at a time when gigabit per second wireless communications is envisioned to bring a fundamental shift to the design of future smart environments. The results of this project will trigger the emerging concept of smart environments, ranging from smart materials controlled or manipulated at the nanoscale, to smart cities with massive deployment of sensors and monitoring systems. In particular, the widespread availability and demand for multimedia capable devices and multimedia content have fuelled the need for high-speed wireless connectivity beyond the capabilities of existing commercial standards. The technologies developed in this project will address practical issues concerning the design and implementation of next generation multi-gigabit

	wireless applications enabling low cost fibre replacement mobile backhauls, last mile wireless broadband access, ultra-dense small cells, low latency uncompressed high-definition media transfers, and wireless access to the cloud. The challenges and fundamental limits of future networked societies can only be mastered by exploring the disruptive potential of low-interference high-speed wireless links for smart and sustainable environments. The results of this project will have immediate impact on advancing the state-of-the-art in mobile and ubiquitous computing for multi-gigabit-per-second data rates, supporting new wireless platforms such as cloud computing and tactile Internet to handle large quantities of data and thus to underpin the Internet of Everything (IoE) as a truly networked society connecting hundreds of billions of people, objects, and services. In particular, the concepts, algorithms, and theory developed in this project will address practical issues concerning the unbalanced temporal and geographical variations of the spectrum, along with the rapid proliferation of bandwidth-hungry mobile applications, such as video streaming with high definition television (HDTV) and ultra-high definition video (UHDV). Even though wireless channel impairments greatly impact the bandwidth efficiency of wireless networks, their effects have not been taken into consideration in the recent research carried out in this discipline, especially in the microwave and millimetre-wave bands for fifth generation (5G) cellular. The objective of this project is to improve the bandwidth efficiency of next generation 5G operating in the microwave and millimetre-wave bands through effective transmitter and receiver designs that exploit massive multiple-input multiple-output (MIMO) and heterogeneous small cell deployment, while taking into account the effects of impairments, such as channel estimation error, phase noise, and carrier frequency offset. As a result, this project is not based on any idealistic assumptions regarding the wireless channel, which compared to existing work in this field is unique. The proposed research certainly raises several fundamental design challenges far from trivial, that have their roots in diverse disciplines, including information theory, stochastic control theory, sequential statistics, large system analysis, automated decision making, and pervasive computing. Industrial partners will be engaged throughout the project to ensure industrial relevance of our work.

Project Title	The UK Programmable Fixed and Mobile Internet Infrastructure (INITIATE)
Lead Organisation	Bristol University
Partners	King’s College London Edinburgh University Lancaster University BBC BT CORSA f5 Networks

	Cambridge Wireless Huawei Interdigital Keysight Konica Minolta Thales, National Instruments pureLifi Ofcom Zeetta Networks Digital Catapult
Funding Source	EPSRC
Funding	£ 1,676,408
Start / End	01/02/2017 - 31/01/2021
5G Classification Terms	NFV, SDN, Optical Network
Weblink	http://gow.epsrc.ac.uk/NGBOViewGrant.aspx?GrantRef=EP/P003974/1
Description (containing objectives, potential outcomes)	INITIATE will create a new, specialist distributed test-bed to facilitate the increasingly large and complex experimentation required for future Internet research. This will be achieved by interconnecting operational, state-of-the-art operational laboratories at the Universities of Bristol, Lancaster (UoLan), Edinburgh (UoEd) and Kings College London (KCL). These laboratories will contribute many key capabilities for Internet research including optical networks, wireless/RF communications, the Internet of Things (IoT), Software Defined Networking (SDN), Network Function Virtualisation (NFV) and cloud computing. Therefore INITIATE will offer the combined capability to the UK Internet research and innovation communities as a single distributed test-bed able to support the increasingly complex experimentation required for future Internet research. For example, INITIATE will enable for the first time experimentally driven research addressing the integration of multi-domain and multi-technology 5G and IoT access platforms with high-speed optical transport and investigate full system optimization strategies. Uniquely, INITIATE will also be able to integrate end-users as part of the experimental process and support user driven scenarios such as mobile edge computing, data visualization and autonomous mobility. The applicants have an outstanding worldwide reputation for creating, maintaining and operating research test-beds. They have repeatedly enabled remote access to their laboratories for experimenters and they have worked in multiple initiatives involving interconnection of research test-beds either locally, across the consortium partners or at a regional, national and international scale. Examples are: Bristol Is Open (UoB), TOUCAN (EPSRC involving UoB, UoEd, UoLan), NDFIS (UoB, UCL,

	SOTON, Cambridge), wireless mesh networks for rural communities (UoLan) and the Ofcom whitespace trial environment (KCL), among others. Internationally, the partners have been involved in numerous Future Internet infrastructure projects such as OFELIA & Fed4FIRE (EU FIRE), FIBRE & FUTEBOL (EU-Brazil), STRAUSS (EU-Japan) and GEANT, where they have delivered test-bed infrastructure, developed experimental control and federation tools and supported user experiments. INITIATE will create an environment for delivering excellence in Internet research, educational and industrial innovation and cross-discipline interaction through experimentally driven national collaboration. The project will also support academia as well as industry and SMEs and will deliver a sustainable engagement model.

Project Title	CROSSFIRE: Uncoordinated network strategies for enhanced interference, mobility, radio resource, and energy saving management in LTE-Advanced networks
Lead Organisation	ETHNIKO KAI KAPODISTRIAKO PANEPISTIMIO ATHINON *
Partners	KING'S COLLEGE LONDON VODAFONE GROUP SERVICES LIMITED NEC EUROPE LTD FUNDACIO PER A LA UNIVERSITAT OBERTA DE CATALUNYA * CENTRE NATIONAL DE LA RECHERCHE * SCIENTIFIQUE CNRS * IQUADRAT INFORMATICA SL * STEINWURF APS *
Funding Source	FP7
Funding	€ 3,439,175.96
Start / End	01/09/2012 - 31/08/2016
5G Classification Terms	NFV, HetNets, Qos/QoE
Weblink	https://cordis.europa.eu/project/rcn/104702_en.html
Description (containing objectives,	The aim of the CROSSIRE project is to provide forward-looking solutions for Long-Term Evolution-Advanced (LTE-A) network co-existence including aspects ranging from the physical layer such as co-

potential outcomes)	channel interference and cognition to the user perception of the service, i.e., Quality of Experience (QoE). The project will analyse and propose network virtualization solutions for LTE-A networks a technology which is envisioned to transform operation of cellular networks in the years to come. The project will approach the emerging LTE-A networks which will be populated by uncoordinated and vast number of small cells (micro, pico and femtocells) from an architectural and a component level perspective. We primary aim to provide a holistic understanding on issues such as co-channel interference from randomly located small-cells (unplanned deployment), efficient utilization of the scarce spectrum (via cognition), self-Organisation (SONs) and QoE at the end users under the assumption that LTE-A networks share a common physical infrastructure. The developed architectures, protocols and techniques will be evaluated through system level simulations and theoretical analysis. A meaningful subset of them will be evaluated through hardware proof-of-concept prototyping.

Project Title	5GCAR: Fifth Generation Communication Automotive Research and Innovation
Lead Organisation	Ericsson *
Partners	ROBERT BOSCH GMBH * CHALMERS TEKNISKA HOEGSKOLA AB * FUNDACION PARA LA PROMOCION DE LA INNOVACION, INVESTIGACION Y DESARROLLO * TECNOLOGICO EN LA INDUSTRIA DE AUTOMOCION DE GALICIA * CENTRE TECNOLOGIC DE TELECOMUNICACIONS DE CATALUNYA * ERICSSON GMBH * HUAWEI TECHNOLOGIES DUESSELDORF GMBH * KING'S COLLEGE LONDON MARBEN PRODUCTSF * NOKIA SOLUTIONS AND NETWORKS SP ZOO * ALCATEL-LUCENT DEUTSCHLAND AG * NOKIA SOLUTIONS AND NETWORKS OY * ORANGE SA * PSA AUTOMOBILES SA * SEQUANS COMMUNICATIONS SA * VISCODA GMBH * VOLVO PERSONVAGNAR AB *
Funding Source	H2020 (5G-PPP)
Funding	€ 7,995,413.75
Start / End	01/06/2017 - 31/05/2019
5G Classification Terms	NFV, MEC (Mobile Edge Computing), Network Slicing, D2D, Automotive

Weblink	https://5gcar.eu/
Description (containing objectives, potential outcomes)	There are two ongoing industrial trends, one in the mobile communications industry and one in the automotive industry, which are becoming interwoven and will jointly provide new capabilities and functionality for upcoming intelligent transport systems and future driving. 5GCAR brings together a strong consortium from the automotive industry and the mobile communications industry, to develop innovation at the intersection of those industrial sectors in order to support a fast, and successful path towards safer and more efficient future driving. Develop the cellular V2X architecture and PoC for V2X use cases (lane merging, vulnerable road user, cooperative perception)

Project Title	VirtuWind: Virtual and programmable industrial prototype deployed in operational wind park
Lead Organisation	Siemens *
Partners	TECHNISCHE UNIVERSITAET MUENCHEN * FOUNDATION FOR RESEARCH AND TECHNOLOGY HELLAS * KING'S COLLEGE LONDON NEC EUROPE LTD INTRACOM SA TELECOM SOLUTIONS * WORLDSENSING SL * DEUTSCHE TELEKOM AG * INTEL RESEARCH AND DEVELOPMENT IRELAND LIMITED *
Funding Source	H2020
Funding	€ 4,874,899.50
Start / End	01/07/2015 - 30/06/2018
5G Classification Terms	NFV, SDN, Network Automation, Network Slicing, IoT - Industry 4.0, Qos/QoE, Security
Weblink	http://www.virtuwind.eu/
Description (containing	VirtuWind will develop and demonstrate SDN & NFV ecosystem, based on open, modular and secure framework showcasing a

objectives, potential outcomes)	prototype for intra-domain and inter-domain scenarios in real wind parks as a representative use case of industrial networks, and validate the economic viability of the demonstrated solution. The wind park control network has been chosen as a professional application in VirtuWind as wind energy has now established itself as a mainstream of sustainable energy generation. By envisioning lower capital expenditure and operational expenditure costs in control network infrastructure, VirtuWind will play important role in assisting wind energy sector to achieve cost reductions. Further applicability of VirtuWind solution in other industrial domains will bring multifold benefits in their communication networks. The VirtuWind consortium consists of strong industry and academic partners covering the whole value chain of programmable networks. The consortium is striving for a common vision of creating industrial capability of SDN/NFV in Europe.

Project Title	5G NORMA - 5G Novel Radio Multiservice adaptive network Architecture
Lead Organisation	Nokia *
Partners	NEC EUROPE LTD REAL WIRELESS LIMITED KING'S COLLEGE LONDON NOKIA SOLUTIONS AND NETWORKS OY * ALCATEL-LUCENT DEUTSCHLAND AG * NOKIA BELL LABS FRANCE * ATOS SPAIN SA * DEUTSCHE TELEKOM AG * ORANGE SA * TELEFONICA INVESTIGACION Y DESARROLLO SA * AZCOM TECHNOLOGY SRL * NOMOR RESEARCH GMBH * TECHNISCHE UNIVERSITAET KAISERSLAUTERN * UNIVERSIDAD CARLOS III DE MADRID *
Funding Source	H2020 (5GPPP)
Funding	€ 7,921,868.75
Start / End	01/07/2015 - 31/12/2017
5G Classification Terms	EPC, NFV, SDN, MEC (Mobile Edge Computing), Network Slicing, Cloud RAN, System Integration / Validation / Simulation, Security
Weblink	http://www.it.uc3m.es/wnl/5gnorma/
Description (containing	The key objective of 5G NORMA is to develop a conceptually novel, adaptive and future-proof 5G mobile network architecture. The

objectives, potential outcomes)	architecture is enabling unprecedented levels of network customisability, ensuring stringent performance, security, cost and energy requirements to be met; as well as providing an API-driven architectural openness, fuelling economic growth through over-the-top innovation. With 5G NORMA, leading players in the mobile ecosystem aim to underpin Europe's leadership position in 5G. Relevant to strands "Radio network architecture and technologies" and "Convergence beyond last mile", the 5G NORMA architecture will provide the necessary adaptability able to efficiently handle the diverse requirements and traffic demand fluctuations resulting from heterogeneous and changing service portfolios. Not following the 'one system fits all services' paradigm of current architectures, 5G NORMA will allow for adapting the mechanisms executed for a given service to the specific service requirements, resulting in a novel service- and context-dependent adaptation of network functions paradigm. The technical approach is based on the innovative concept of adaptive (de)composition and allocation of mobile network functions, which flexibly decomposes the mobile network functions and places the resulting functions in the most appropriate location. By doing so, access and core functions no longer (necessarily) reside in different locations, which is exploited to jointly optimize their operation when possible. The adaptability of the architecture is further strengthened by the innovative software-defined mobile network control and mobile multi-tenancy concepts, and underpinned by corroborating demonstrations. 5G NORMA will ensure economic sustainability of network operation and open opportunities for new players, while leveraging the efficiency of the architecture to do so in a cost- and energy- effective way.

Project Title	UPON: Ultimate Passive Optical Network
Lead Organisation	Aston University
Partners*	Phoenix Sterlite Technologies Ltd
Funding Source	EPSRC
Funding	£777,148
Start / End	01/07/2015 - 30/06/2019
5G Classification Terms	Optical Network
Weblink	http://gow.epsrc.ac.uk/NGBOViewGrant.aspx?GrantRef=EP/M005283/1
Description (containing	The project will identify the network configuration which allows the maximum possible capacity per user (with a single connection),

objectives, potential outcomes)	considering both the limitations of the access network itself (arising from trade-off between nonlinearity and noise) and the practically achievable capacity in the core network. By considering techno-economic modelling as a fundamental component of the network design, with equal weight to technological constraints, will also identify, propose and demonstrate cost effective evolution scenarios.

Project Title	IoRL: Internet of Radio Light
Lead Organisation	Eurescom *
Partners*	Brunel University Cobham Wireless BRE Group ISEP * MostlyTek Ltd * Issy Média * Fraunhofer Institute for Integrated Circuits IIS * National Centre for Scientific Research Demokritos * Viotech * Warsaw University of Technology * Arçelik A.S. * RunEL * Holon Institute of Technology * Ferrovial sa * Oledcomm * Tsinghua University * Leadpcom * Shanghai-Feilo/ Yaming * Centre for Innovation in Smart Infrastructures (CI3) *
Funding Source	H2020 (5G-PPP)
Funding	€ 7,685,423.75
Start / End	01/06/2017 - 31//05/2020
5G Classification Terms	NFV, SDN, Optical Network, mmWAVE
Weblink	https://iorl.5g-ppp.eu/
Description (containing objectives, potential outcomes)	IoRL project provides solutions to the two main barriers to develop this broadband networking solution in buildings because it: (i) Brings together a multi-disciplinary team of research institutions and industries in a collaborative project to develop and demonstrate this vision, who otherwise would not have assembled to achieve this goal; (ii) Develops a proof of concept demonstrator, which will act as the basis for standardization of a global solution. The starting point

	is the joint VLC demonstrator at Tsinghua University & ISEP, the mmWave at Cobham Wireless and the NFV/SDN at NCSR-Democratos. The challenges are to (i) Develop broadband communication solutions for buildings by integrating these technologies to exploit the pervasiveness and accessibility of the existing electric light access points, the broadband capacities of mmWave and VLC technologies and the flexibility of SDN/NFV; (ii) Industrially design a radio-light solution that can be integrated into the myriad of form factors of existing electric light systems and consumer products.

Project Title	Compound Semiconductor Underpinning Equipment
Lead Organisation	Cardiff University
Partners*	IQE Plc Compound Semiconductor Centre
Funding Source	EPSRC
Funding	£2,000,000
Start / End	01/04/2017 - 31/03/2018
5G Classification Terms	Other
Weblink	http://gow.epsrc.ac.uk/NGBOViewGrant.aspx?GrantRef=EP/P030556/1
Description (containing objectives, potential outcomes)	Compound Semiconductor (CS) materials are a Key Enabling Technology at the heart of modern society. They are central to the development of, for example, the 5G network, new energy efficient lighting, smart phones, satellite communications systems, power electronics for the next generation of electric vehicles and new imaging techniques. Simply put, these technologies support our connected world, our health, our security and the environment. The next generation of these technologies can only be achieved with a step change in CS manufacturing and we aim to the UK at the centre of this CS manufacturing research. This is not only important activity in its own right but will also support systems researchers in all of these important fields. The step change will be achieved by applying the manufacturing disciplines and approaches of Silicon to Compound Semiconductors and by combining CS with Silicon. This includes developing integrated epitaxial growth and processing with critical yield and reliability analysis; establishing new standards for CS device production, with a guaranteed number of wafer starts per week for key statistical based process control

	and development via IT infrastructure; solving the scientific and manufacturing challenges in wafer size scale-up combining large scale, 150-200mm diameter growth and fabrication for GaAs based and GaN based materials and apply this to existing and developed advanced processes; introducing a multi-project wafer culture (as is the norm in the silicon world) to share costs and encourage the widespread use of larger wafers by academics and SMEs. Critical to this approach is the characterisation equipment, which can be used in-line (during the manufacturing process) and over the larger (up to 200mm diameter) CS wafers we will utilise. This proposal is for this characterisation equipment to add to the large investment already made by Cardiff University and partners in epitaxial growth and fabrication infrastructure and equipment. We also ask for apparatus to allow high quality insulating layers to be deposited, which will enable the multi-project wafer approach to produce world leading performance, for access by our UK based circuit and system designers.

Project Title	GigaMobile: Gigabit Mobile Networking using Incentivised Operator Controlled Device-to-Device Communications
Lead Organisation	Cardiff University
Partners*	Keima Telefonica (O_2) Samsung Queen's University Belfast
Funding Source	EPSRC
Funding	£534,918
Start / End	31/12/2014 - 30/12/2017
5G Classification Terms	D2D, Routing
Weblink	http://gtr.rcuk.ac.uk/projects?ref=EP%2FL026074%2F1
Description (containing objectives, potential outcomes)	This project proposes a new paradigm for ultra-high capacity mobile networks by simultaneously and jointly addressing the bandwidth problem and the dynamic network management issues associated with device-to-device communications. The project will focus on understanding and exploiting incentivised, multimode user equipment operating as an ultra-high capacity underlay

	network featuring real-time opportunistic adaptive routing all overseen by a context aware mobile network infrastructure.

Project Title	A Feasibility Study for the Development of GaN - based High Frequency RF Devices
Lead Organisation	Compound Semiconductor Centre Limited
Partners	Cardiff University University of Glasgow
Funding Source	Innovate UK
Funding	£148,843
Start / End	10/2017 - 09/2018
5G Classification Terms	Radio Front-end / RF, Other
Weblink	http://gtr.rcuk.ac.uk/projects?ref=103440
Description (containing objectives, potential outcomes)	The UK has some of the world's leading designers of microwave systems and some of the leading test and characterising expertise for gallium nitride - based RF devices but it does not capitalise on this and has no sovereign or accessible industrial manufacturing capability. These devices are fundamental to many space systems, military communication and guidance systems and will be essential in the roll out of the upcoming "5G" communications revolution. To capitalise on the UK's expertise and to provide a world class strategic sovereign capability in advanced communications technology, the CSC Ltd is leading this feasibility project to develop a base-line RF gallium nitride (GaN) on silicon carbide (SiC) structure that can be incorporated into a high electron mobility transistors (HEMTs) for the so called Ka-band (26.5–40.0GHz) of communication frequencies and beyond. The outcomes from this feasibility project are ultimately targeted at enabling the collaborators to access the rapidly growing GaN - based RF markets worth $350M and forecast to grow to $750M by 2022.

Project Title	Towards Ultimate Convergence of All Networks (TOUCAN)
Lead Organisation	University of Bristol
Partners	Technology Strategy Board Plextek Ltd, Great Chesterford Samsung Electronics BT Laboratories JANET UK

	NEC Telecom MODUS Ltd Broadcom UK Ltd Bristol City Council
Funding Source	EPSRC
Funding	£5,893,499
Start / End	08/2014 - 09/2019
5G Classification Terms	Qos/QoE, SDN, Optical Network, NFV
Weblink	http://gtr.rcuk.ac.uk/project/89D511E1-6C17-4D76-BC95-490B420DDC58
Description (containing objectives, potential outcomes)	TOUCAN aims to achieve ultimate network convergence enabled by a radically new technology agnostic architecture targeting a wide range of applications and end users. This architecture will facilitate optimal interconnection of any network technology domains, networked devices and data sets with high flexibility, resource and energy efficiency, and will aim to satisfy the full range of Quality of Service (QoS) and Quality of Experience (QoE) requirements. TOUCAN will realise its goals by including the network infrastructure and its control as part of the end-to-end service delivery chain. Important enablers will be that of separating the data and control planes, which will rely on Software Defined Networking (SDN) principles. TOUCAN will drastically evolve SDN to incorporate fundamentally new technology-specific interfacing and resource description followed by infrastructure resource abstraction, virtualisation and programmability. These features will enable any network technology and device to become "TOUCAN-ready" which means that the devices are programmable and interoperable. This is the foundation upon which the technology-agnostic feature of the TOUCAN architecture will be realized; thereby ultimate seamless end-to-end convergence will be achieved. The most direct impact will target the Programme Industrial Partners (BROADCOM, BT, NEC, Plextek, and Samsung). All Programme Partners have been engaged in the shaping of the TOUCAN vision, which they consider to be critical for their future technology roadmaps, as demonstrated by the significant amount of resources committed to the project. It is expected that new industrial partners will join the initial team as the research unfolds and TOUCAN is being established as a world-leading research project. To engage the wider industrial sector, we plan a series of 5 Industrial Workshops during the Programme lifetime. To ensure broad industrial participation in these events, we will work closely with the Strategic Advisory Board (SAB: BBC, IBM, DoCoMo, Deutsche Telekom,

	iMinds, i2CAT, University of Leeds) and fora such as the ICT-KTN, the Local Enterprise Partnerships, Mobile VCE, GreenTouch, and EU technology platforms (e.g. Net!Works and Photonics21). A further key activity to achieving sustainable impact will be contributions to industry standards (e.g. ITU-T, ETSI, IETF, TMF) and to a number of new SDN-focused standard bodies in which we will engage, including ONF, Open Daylight and Open Stack. Where standards and specification gaps exist we will look to initiate new standards or even create new working groups.

Project Title	Large Scale Antenna Systems Made Practical: Advanced Signal Processing for Compact Deployments [LSAS-SP]
Lead Organisation	UCL
Partners	QinetiQ Heriot-Watt University Alcatel Lucent * Athens Information Technology AIT *
Funding Source	EPSRC
Funding	£546,587
Start / End	04/2015-09/2018
5G Classification Terms	Massive / MU-MIMO, Radio Front-end / RF, Antenna, Baseband/ Signal processing
Weblink	http://gow.epsrc.ac.uk/NGBOViewGrant.aspx?GrantRef=EP/M014150/1 http://gow.epsrc.ac.uk/NGBOViewGrant.aspx?GrantRef=EP/M014126/1
Description (containing objectives, potential outcomes)	This project investigates signal processing techniques for practical and realistic implementations of large-scale antenna systems (LSAS) for energy- and spectral- efficient wireless communication. This project tackles the issue of large scale antenna deployment by a) information theoretical analysis with realistic modelling, b) signal processing and CSI acquisition devoted to power efficiency and c) analogue-digital beamforming designs and reduced RF-chain solutions aimed at power- and cost- effective implementations. The project aims to achieve power-efficient transmission by large scale antenna systems based on two key disruptive concepts: a) using analogue beamforming using the principles of Electrically-Steerable Parasitic Array Radiators (ESPAR) based LSAS and b) exploiting constructive interference. In addition, this project re-examines the anticipated benefits of LSAS from the

	viewpoint of realistic deployments of the antenna arrays in limited physical space which are prone to increased correlation and coupling between the densely deployed antennas. We aim at a thorough and pragmatic investigation of the benefits of LSAS for Green Communications, and their practical implementation solutions.

Project Title	A Unified Multiple Access Framework for Next Generation Mobile Networks By Removing Orthogonality (MANGO)
Lead Organisation	Heriot-Watt University
Partners	Nokia QinetiQ Samsung VCE Mobile & Personal Comm Ltd
Funding Source	EPSRC
Funding	£328,990
Start / End	01/08/2017 - 31/07/2020
5G Classification Terms	Baseband/ Signal processing, MAC / RRM
Weblink	http://gow.epsrc.ac.uk/NGBOViewGrant.aspx?GrantRef=EP/P009670/1
Description (containing objectives, potential outcomes)	Motivated by the spectral inefficiency of OMA techniques, non-orthogonal multiple access (NOMA) has been recognised recently as a promising multiple access technique to significantly enhance the spectral efficiency and is envisioned to be a key component of the next generation mobile networks. The dominant NOMA schemes are grouped in two categories: power-domain or code-domain NOMA. In power-domain NOMA, users are allocated different power levels according to their channel conditions to obtain the maximum gain in system performance whereas in code-domain NOMA, different users are assigned different codes, and are then multiplexed over the same time-frequency resources. However, NOMA techniques still involve several critical challenges such as lack of insightful understanding of the performance limits of NOMA and a large gap in the performance evaluation of NOMA transceivers under single-/multiple antennas, single-/multi-cell cases, which makes their immediate deployment prohibitive. This visionary project tackles the issue of NOMA techniques' deployment in next generation mobile networks by establishing a unified theoretical framework and developing sophisticated digital signal processing algorithms to realise the concept of NOMA in single-/multiple antenna,

	single-/multi-cell scenarios. The novelty of this project lies in a) information theoretical analysis with practical constraints, b) less-computationally complex transceiver design for power-domain and code-domain NOMA c) joint precoding design for single- and multi-cell NOMA networks, d) NOMA applications in cognitive radio and IoT systems and e) system level performance evaluations in next generation mobile network scenarios.

Project Title	MIMO Wireless Networks: A promising Rate Splitting Transceiver Architecture
Lead Organisation	Edinburgh University
Partners	Imperial College London InterDigital QinetiQ Toshiba
Funding Source	EPSRC
Funding	£594,215
Start / End	05/2016 - 05/2019
5G Classification Terms	Massive / MU-MIMO, mmWAVE, Antenna, Baseband/ Signal processing
Weblink	http://gow.epsrc.ac.uk/NGBOViewGrant.aspx?GrantRef=EP/N015312/1 http://gow.epsrc.ac.uk/NGBOViewGrant.aspx?GrantRef=EP/N014073/1
Description (containing objectives, potential outcomes)	In this project, we leverage recent progress in information theory and initial results by the PIs to address the above fundamental CSIT problem (and its resulting multi-user interference) by introducing a rate-splitting (RS) network architecture. Contrary to current approaches where transmission is operated in a broadcast manner with one private message per user, the approach considered consists in splitting one receiver's message into a common and a private part and superposing this common message on top of all users' private messages. The common message is decoded by all users but intended to only one of the users. Such approach has recently been found to be optimal from an information theoretic perspective in a multiuser deployment with imperfect CSIT and significant enhancements over conventional approaches in terms of spectral efficiency and power utilization have been demonstrated by the PIs. This visionary project conducted at Imperial College London and University of Edinburgh by leading experts in wireless communication theory aims at leveraging those recent findings to design and demonstrate the suitability of an RS-based MIMO wireless network architecture in a multitude of scenarios.

	To put together this novel wireless network solution in a credible fashion, this project focuses on designing 1) RS for a single transmission point, 2) RS for a large number of co-localized antennas (also called Massive MIMO) in microwave and millimetre-wave bands, 3) RS for a large number of distributed antennas representative of dense heterogeneous networks, 4) RS for multi-antenna relay channel and finally 5) evaluating the system level performance of RS-based networks. The project will be performed in partnership with leaders in equipment manufacturing and standardization (Toshiba and InterDigital) and in defence and emergency services (QinetiQ). The project demands a strong track record in wireless communication, MIMO signal processing, optimization, information theory and it is to be conducted in a unique research group with a right mix of theoretical and practical skills. With the above and given the novelty and originality of the topic, the research outcomes will be of considerable value to transform the future of wireless and give the industry a fresh and timely insight into the development of robust MIMO wireless networks, advancing UK's research profile of both wireless communication in the world. Its success would radically change the design of the physical layer of wireless communication systems and have a tremendous impact on standardization.

Project Title	OrganiCity – Co-creating smart cities of the future
Lead Organisation	Aarhus University *
Partners	INTEL CORPORATION (UK) LIMITED ALEXANDRA INSTITUTTET A/S * FUTURE CITIES CATAPULT LIMITED IMPERIAL COLLEGE OF SCIENCE TECHNOLOGY AND MEDICINE TECNOLOGIAS SERVICIOS TELEMATICOS Y SISTEMAS S.A. * LULEA TEKNISKA UNIVERSITET * INSTITOUTO TECHNOLOGIAS YPOLOGISTONKAI EKDOSEON DIOFANTOSG * UNIVERSITAT ZU LUBECK * INSTITUT D'ARQUITECTURA AVANCADA DE CATALUNYA * COMMISSARIAT A L ENERGIE ATOMIQUE ET AUX ENERGIES ALTERNATIVES * UNIVERSIDAD DE CANTABRIA * ARHUS KOMMUNE * AYUNTAMIENTO DE SANTANDER * UNIVERSITY OF MELBOURNE *
Funding Source	H2020
Funding	€ 7,266,582
Start / End	01/01/2015 - 30/06/2018
5G Classification	IoT - Smart Cities

Terms	
Weblink	http://organicity.eu/
Description (containing objectives, potential outcomes)	OrganiCity offers a new paradigm to European digital city making. Built on and extending the FIRE legacy, this project seeks to build a strong foundation for future sustainable cities through co-creation by a wide range of stakeholders. Globally, Europe is a champion of sustainable, inclusive and open societies. The digital age enables us to push this position further and to rethink the way we create cities and facilitate living by integrating many complex systems. OrganiCity combines top-down planning and operations with flexible bottom-up initiatives where citizen involvement is key. So far, this has been difficult to achieve. Previous attempts to scale informal one-off projects or broaden single community projects have failed. By focusing on the city as a sociotechnical whole, OrganiCity brings software, hardware and associated human processes flexibly together into a new living city that is replicable, scalable, as well as socially, environmentally and economically sustainable. Three clusters – Aarhus (DK), London (UK) and Santander (ES) – recognised for their digital urban initiatives, bring their various stakeholders together into a coherent effort to develop an integrated Experimentation-as-a-Service facility respecting ethical and privacy sensitivities and potentially improving the lives of millions of people. The OrganiCity consortium will create a novel set of tools for civic co-creation, well beyond the state of the art in trans-disciplinary participatory urban interaction design. The tools will be validated in each cluster and integrated across the three cities. In addition to citizen-centric join of testbeds, partner technologies and enhancements, two open calls with a budget of €1.8M will permit 25-35 experiments to use the new facility and co-creation tools. The aim is to grow sustainable digital solutions for future cities that are adjusted to the culture and capacities of each city unlocking amended services and novel markets.

Project Title	PhyLAWS: Physical Layer Wireless Security
Lead Organisation	Thales *
Partners	Imperial College London VTT * INSTITUT MINES-TELECOM * CELENO COMMUNICATIONS ISRAEL LTD *
Funding Source	FP7
Funding	€ 2,810,186
Start / End	01/11/2012 - 31/10/2016
5G Classification Terms	Security, Baseband/ Signal processing

Weblink	http://www.phylaws-ict.org/
Description (containing objectives, potential outcomes)	One of the weaknesses of wireless communications is the easy capture of the radiated signals by eavesdroppers, which enhances the risks of using these signals or acting on them by un-authorized persons. Given the prevalence of wireless technologies, their security and the reliability a person or an Organisation can have in the confidentiality of the exchanged information can be seen as a major economic and industrial challenge. Focusing on physical based security, the PHYLAWS project intends to address the improvement of the protection and confidentiality of information exchanged at physical interface through public wireless media by several means:· Identify the most promising security techniques operating at the physical layer level or exploiting the characteristics of signals transmitted at the physical layer. Identify the existing, upcoming of future systems, where these techniques might be implemented, without or with updates to the standards.· Carry out theoretical, simulation based and experimental performance evaluation of these techniques, taking into account realistic radio-electrical environments, relevant propagation parameters and use conditions. Develop the suitable algorithms where necessary.· Demonstrate the capabilities of a selection of techniques in enhancing the information protection and the subscriber confidentiality.· Demonstrate the capabilities of the selected techniques in reducing the redundancy of radio-communication signals, in enhancing the spectrum usage and the energy efficiency)The targeted protections will apply to a significant set of public wireless systems or standards: 2/3/4G radio-cell, local loop, private mobiles radios, inter-device short range communications, etc. The impact will be societal (more confidence, more privacy) and industrial (supporting European industry in developing and commercializing such solutions). The project should strongly influence the suitable standardization bodies, where needed and relevant.

Three: UK based industry projects

Project Title	1400 mini masts to boost reception before 5G roll out
Lead Organisation	**O_2**
Partners	N/A
Funding Source	N/A
Funding	N/A
Start / End	N/A
5G Classification Terms	Infrastructure, HetNet
Weblink	http://www.cityam.com/264498/o2-prepares-london-5g-plans-put-up-1400-mobile-phone-masts
Description (containing objectives, potential	Project is in place for 1400 mini masts to be placed around London.

outcomes)	

Project Title	City of Aberdeen paves the way for 5G thanks to Wireless Infrastructure Group and O_2
Lead Organisation	**O_2**
Partners	WIG, City of Aberdeen
Funding Source	N/A
Funding	N/A
Start / End	N/A
5G Classification Terms	Infrastructure, Cloud RAN, HetNet
Weblink	http://www.wirelessinfrastructure.co.uk/city-of-aberdeen-paves-the-way-for-5g/
Description (containing objectives, potential outcomes)	Wireless Infrastructure Group (WIG) and O_2 have partnered to launch the UK's first fibre-connected small cell network, supporting C-RAN technology for faster and higher capacity mobile services. Accelerate Aberdeen is an ambitious programme of work to provide Aberdeen with the world class infrastructure and business development platforms to secure the long term vibrancy of the city's economy. As part of this programme, Aberdeen City Council has a Wireless Concession with Wireless Infrastructure Group (WIG) enabling the deployment of small cells within the city centre and beyond by allowing access to the Council's street furniture and buildings. Aberdeen City Region Deal area has also been selected as one of the pilot areas to deliver full fibre connection vouchers to meet the cost of fibre to the premises roll out in the region.

Project Title	Partnerships with other companies to plan path to 5G
Lead Organisation	**Vodafone**
Partners	Huawei, Nokia, Ericsson, Intel and Qualcomm Technologies
Funding Source	N/A
Funding	N/A
Start / End	N/A
5G Classification	Automotive, Massive/MU-MIMO, MAC/RRM, Other

Terms	
Weblink	http://www.telecomtv.com/articles/5g/vodafone-shows-its-5g-credentials-and-joins-the-party-14024/
Description (containing objectives, potential outcomes)	Project is in place for 1400 mini masts to be placed around London.

Project Title	**Ericsson** partnership to provide Vodafone UK with 5G Radio technology to prepare for the introduction of 5G in southern England
Lead Organisation	**Vodafone**
Partners	**Ericsson**
Funding Source	N/A
Funding	N/A
Start / End	N/A
5G Classification Terms	Massive / MU-MIMO
Weblink	https://www.ericsson.com/en/press-releases/2017/6/vodafone-uk-selects-ericsson-technology-to-evolve-london-network
Description (containing objectives, potential outcomes)	Ericsson has been selected to provide Vodafone UK with 5G Radio technology to prepare for the introduction of 5G in the region

Project Title	Qualcomm, EE, Sony come together for Gigabit LTE demo
Lead Organisation	**EE**
Partners	**Qualcomm, EE, Sony**
Funding Source	N/A
Funding	N/A
5G Classification Terms	Other
Start / End	N/A
Weblink	https://www.itproportal.com/news/5g-moves-one-step-closer-with-gigabit-lte-network/
Description	A live test at London's Wembley Stadium, the new network

(containing objectives, potential outcomes)	reached a download speed of 698MBps - quick enough to download an 4K-quality film in a matter of seconds, and up to twice as fast as the UK quickest commercial fibre broadband offering. The development is helping the company on its way to launching 5G networks in time for the 2020 deadline.

Project Title	Built a complete 5G network in their test lab, simulating the real world in **Hertfordshire**
Lead Organisation	**EE**
Partners	**BT, Huawei,**
Funding Source	N/A
Funding	N/A
Start / End	N/A
5G Classification Terms	Massive / MU-MIMO, Network Slicing, RAN, NFV
Weblink	https://5g.co.uk/news/ee-builds-a-5g-network-in-lab-to-validate-5g-architecture/4228/
Description (containing objectives, potential outcomes)	Demonstrating an end-to-end 5G network architecture broadcasting in 5G New Radio (5G NR) with 64x64 massive MIMO on the antenna array, EE claimed that its achievement went way further than consistent 2.8Gbps download rates.

Project Title	Three's new service will use the high-frequency radio spectrum it will acquire in the ongoing £250m takeover of UK Broadband Relish
Lead Organisation	**Three**
Partners	Relish
Funding Source	N/A
Funding	N/A
Start / End	N/A
5G Classification Terms	FWA, Other
Weblink	http://www.telegraph.co.uk/business/2017/05/01/three-plans-

	blanket-cities-5g-network/
Description (containing objectives, potential outcomes)	Three's new service will use the high-frequency radio spectrum it will acquire in the ongoing £250m takeover of UK Broadband, the London-only wireless broadband provider behind the Relish brand. The spectrum is in the 3.4Ghz range

Project Title	5G Unified Enablement Platform
Lead Organisation	**Cisco**
Partners	N/A
Funding Source	N/A
Funding	N/A
Start / End	N/A
5G Classification Terms	Platform
Weblink	https://www.cisco.com/c/en/us/solutions/service-provider/mobile-internet/5g-infographic.html
Description (containing objectives, potential outcomes)	5G innovation enabling platform Cisco has made ready to use for any companies developing technology in this space

Project Title	**BT Nokia Research collaboration**
Lead Organisation	**BT**
Partners	**Nokia**
Funding Source	N/A
Funding	N/A
Start / End	N/A
5G Classification Terms	mmWAVE, HetNets, Other
Weblink	http://home.bt.com/tech-gadgets/future-tech/bt-and-nokia-to-collaborate-on-development-of-5g-11364080303221
Description (containing objectives, potential	The trials will focus on the technology enablers for 5G including mmWave radio and convergence, as well as potential commercial services including ultrafast mobile

outcomes)	broadband, mission-critical services and the 'Internet of Things' (IoT).

Project Title	BT Huawei Research collaboration in 5G network slicing
Lead Organisation	**BT**
Partners	**Huawei**
Funding Source	N/A
Funding	N/A
Start / End	N/A
5G Classification Terms	Network Slicing
Weblink	http://home.bt.com/tech-gadgets/future-tech/bt-and-huawei-research-5g-network-slicing-11364158147163
Description (containing objectives, potential outcomes)	BT and Huawei announced new research into how 'network slicing' – a method of carving out specific 'slices' of an IP-based network for dedicated purposes – may be used to support services delivered over tomorrow's 5G networks.

Project Title	BT Nokia 5G VR collaboration Project
Lead Organisation	**BT**
Partners	**Nokia**
Funding Source	N/A
Funding	N/A
Start / End	N/A
5G Classification Terms	Media (AR/VR), Massive/MU-MIMO, Cloud RAN,
Weblink	http://home.bt.com/tech-gadgets/future-tech/bt-and-nokia-to-collaborate-on-development-of-5g-11364080303221
Description (containing objectives, potential outcomes)	The research will examine how the low latencies and high bandwidth of 5G can make the most of watching live sport or entertainment using Virtual Reality.

Project Title	5G PPP - NGPaas:NGPaaS: Next Generation Platform as a Service
Lead Organisation	Nokia Bell Labs *

Partners	ONAPP LIMITED VIRTUAL OPEN SYSTEMS * ALCATEL-LUCENT ISRAEL LTD *I ORANGE SA * ATOS SPAIN SA * B-COM * DANMARKS TEKNISKE UNIVERSITET * INTERUNIVERSITAIR MICRO-ELECTRONICA CENTRUM * UNIVERSITA' DEGLI STUDI DI MILANO-BICOCCA * VERTICAL M2M * BRITISH TELECOMMUNICATIONS PUBLIC LIMITED COMPANY
Funding Source	EU (5G-PPP)
Funding	€ 5,214,705.63
Start / End	01/06/2017- 31/05/2019
5G Classification Terms	NFV, SDN, Network Automation, Network Slicing, EPC, Agriculture, Other
Weblink	http://ngpaas.eu/
Description (containing objectives, potential outcomes)	Cloud innovations have had a major impact on the IT industry but not yet on networks. The danger is that 5G will be a niche industry providing basic connectivity for the cloud applications and services boom. The NGPaaS project envisages 5G as: a build-to-order platform, with components, features and performance tailored to a particular use case; developed through a “Dev-for-Operations” model that extends the IT industry’s DevOps approach to support a multi-sided platform between operators, vendors and verticals; and with revised Operational and Business Support Systems (OSS/BSS) to reflect the new parameters and highly dynamic environment. NGPaaS can enable 5G to become central to a cooperative future with cloud developers, by removing the technological silos between the telco and IT industries. NGPaaS builds on 5G-PPP phase 1 projects and lays the foundation for large-scale phase 3 deployments and industrial usage, through a stepped validation of several Telco, IoT/vertical and combined scenarios culminating in a live test in Paris-Saclay campus that can incorporate innovative SMEs selected for showcasing NGPaaS’s operational, service and business benefits.

Project Title	**Fixed Wireless Network trial in partnership with Samsung**
Lead Organisation	**Arqiva**
Partners	**Samsung**
Funding Source	N/A

Funding	N/A
Start / End	N/A
5G Classification Terms	mmWAVE, Media (AR/VR), FWA
Weblink	https://news.samsung.com/global/arqiva-and-samsung-kick-off-uks-first-5g-fixed-wireless-access-trial
Description (containing objectives, potential outcomes)	Powered by Samsung's 5G network solution and customer premises equipment (CPE), and using Arqiva's 28GHz millimetre wave (mmWave) spectrum, the 5G FWA system consists of three main components: Radio Accessed Unit (RAU), CPE, virtualised core.

Project Title	Arqiva and Dali Wireless Collaborate to Cover Glasgow City Centre with Updated Cellular Network
Lead Organisation	**Arqiva**
Partners	**Dali Wireless**
Funding Source	N/A
Funding	N/A
Start / End	N/A
5G Classification Terms	Infrastructure upgrade - RAN
Weblink	https://www.arqiva.com/news/press-releases/arqiva-and-dali-wireless-collaborate-to-cover-glasgow-city-centre-with-updated-cellular-network/
Description (containing objectives, potential outcomes)	Arqiva worked with equipment manufacturer Dali Wireless and system integrator Cellular Asset Management on the upgrade by replacing the analogue components with Dali's digital DAS to provide superior performance and to support 2G, 3G, 4G and future 5G services. The installation in Glasgow is Dali Wireless's first in the UK.

Project Title	Metis II:Mobile and wireless communications Enablers for Twenty-twenty (2020) Information Society-II
Lead Organisation	Ericsson *
Partners	ALCATEL-LUCENT DEUTSCHLAND AG * DEUTSCHE TELEKOM AG * DOCOMO COMMUNICATIONS LABORATORIES EUROPE GMBH * KABUSHIKI GAISHA ENU TI TI DOKOMO * HUAWEI TECHNOLOGIES DUESSELDORF GMBH *

	HUAWEI TECHNOLOGIES CO LTD * INSTITUT DE L'AUDIOVISUEL ET DES TELECOMMUNICATIONS EN EUROPE - IDATE * INTEL DEUTSCHLAND GMBH * INDUSTRIAL TECHNOLOGY RESEARCH INSTITUTE INCORPORATED * JANMEDIA INTERACTIVE SPOLKA Z OGRANICZONA ODPOWIEDZIALNOSCIA * KUNGLIGA TEKNISKA HOEGSKOLAN * NOKIA SOLUTIONS AND NETWORKS MANAGEMENT INTERNATIONAL GMBH * NOKIA SOLUTIONS AND NETWORKS OY * NOKIA SOLUTIONS AND NETWORKS SP ZOO * ORANGE SA * SAMSUNG ELECTRONICS (UK) LIMITED TELECOM ITALIA SPA * TELEFONICA INVESTIGACION Y DESARROLLO SAS * TECHNISCHE UNIVERSITAET KAISERSLAUTERN * UNIVERSITAT POLITECNICA DE VALENCIA * RUTGERS, THE STATE UNIVERSITY OF NEW JERSEY * NEW YORK UNIVERSITY *
Funding Source	EU (5G-PPP)
Funding	€ 7,990,415.50
Start / End	01/05/2015 - 30/06/2017
5G Classification Terms	MAC/RRM, HetNet, Other
Weblink	https://metis-ii.5g-ppp.eu/
Description (containing objectives, potential outcomes)	Key objectives of METIS-II are to develop the overall 5G radio access network design and to provide the technical enablers needed for an efficient integration and use of the various 5G technologies and components currently developed. The innovation pillars that will allow METIS-II to achieve this goal are • a holistic spectrum management architecture addressing the spectrum crunch, • an air interface harmonisation framework enabling an efficient integration of new and legacy air interfaces, • an agile Resource Management (RM) framework providing the dynamics required to efficiently adapt the integrated 5G air interfaces and radio concepts to the varying traffic demand and service requirements, • a cross-layer and cross-air-interface system access and mobility framework ensuring an ubiquitous access continuum, • and a common control and user plane framework providing the means for an efficient support of the broad versatility of services expected for 5G as well as a future-proof and cost-efficient implementation of the 5G integration.

Project Title	One5G:E2E-aware Optimizations and advancements for the Network Edge of 5G New Radio
Lead Organisation	ALCATEL-LUCENT DEUTSCHLAND AG *
Partners	ORANGE SA * AALBORG UNIVERSITET * B-COM * CENTRE NATIONAL DE LA RECHERCHE SCIENTIFIQUE CNRS * FRAUNHOFER GESELLSCHAFT ZUR FOERDERUNG DER ANGEWANDTEN FORSCHUNG E.V. * FREIE UNIVERSITAET BERLIN HUAWEI TECHNOLOGIES DUESSELDORF GMBH * INTEL DEUTSCHLAND GMBH * NOKIA SOLUTIONS AND NETWORKS DANMARK AS * SAMSUNG ELECTRONICS (UK) LIMITED TELEFONICA INVESTIGACION Y DESARROLLO SA * UNIVERSIDAD DE MALAGA * WINGS ICT SOLUTIONS INFORMATION & COMMUNICATION TECHNOLOGIES EPE *
Funding Source	H2020 (5G-PPP)
Funding	€ 7,977,228.75
Start / End	01/06/2017 - 31/05/2019
5G Classification Terms	Massive / MU-MIMO, MAC/RRM
Weblink	https://one5g.eu/
Description (containing objectives, potential outcomes)	To propose 5G NR extensions for standardization which enable high-performance, cost-efficient wireless services in ‘Megacities’ – e.g. dense urban environments with very heterogeneous requirements – and ‘Underserved Areas’— e.g. less populated and with relatively homogeneous requirements. To develop advanced 5G technologies and enhancements, beyond release 15 of 3GPP, which will deliver the first set of 5G standards in 2018. These advanced technologies include future-proof access schemes, advanced massive MIMO enablers and link management To deliver on 5G NR performance optimization schemes for successful network deployment and operation with a focus on improved performance experience for both, the network operator and the E2E user; To identify and improve the cost driving elements in roll-outs and operations in order to allow for the sustainable provision of wireless services in underserved areas under constrained circumstances.

Project Title	Fantastic 5:Flexible Air iNTerfAce for Scalable service delivery within wireless Communication networks of the 5th Generation
Lead Organisation	ALCATEL-LUCENT DEUTSCHLAND AG *
Partners	ORANGE SA * AALBORG UNIVERSITET * COMMISSARIAT A L ENERGIE ATOMIQUE ET AUX ENERGIES ALTERNATIVES * CENTRE TECNOLOGIC DE TELECOMUNICACIONS DE CATALUNYA * FRAUNHOFER GESELLSCHAFT ZUR FOERDERUNG DER ANGEWANDTEN FORSCHUNG E.V. * HUAWEI TECHNOLOGIES DUESSELDORF GMBH * INTEL DEUTSCHLAND GMBH * NOKIA SOLUTIONS AND NETWORKS DANMARK AS * NOKIA SOLUTIONS AND NETWORKS OY * NOKIA SOLUTIONS AND NETWORKS MANAGEMENT INTERNATIONAL GMBH * POLITECNICO DI BARI * SAMSUNG ELECTRONICS (UK) LIMITED SEQUANS COMMUNICATIONS SA * INSTITUT MINES-TELECOM * TELECOM ITALIA SPA * UNIVERSITAET BREMEN * WINGS ICT SOLUTIONS INFORMATION & COMMUNICATION TECHNOLOGIES EPE *
Funding Source	H2020 (5G-PPP)
Funding	€ 7,986,858
Start / End	01/07/2015 - 30/06/2017
5G Classification Terms	Massive / MU-MIMO, MAC / RRM, Mobile Edge Computing (MEC), HetNets
Weblink	https://5g-ppp.eu/fantastic-5g/
Description (containing objectives, potential outcomes)	The intention of FANTASTIC-5G has been to develop, investigate and propose the air interface (AI) for 5G New Radio (NR) for the frequency region below 6 GHz.

Project Title	5G Monarch: 5G Mobile Network Architecture for diverse services, use cases, and applications in 5G and beyond
Lead Organisation	NOKIA SOLUTIONS AND NETWORKS MANAGEMENT INTERNATIONAL GMBH *
Partners	UNIVERSIDAD CARLOS III DE MADRID * DEUTSCHE TELEKOM AG * NOKIA BELL LABS FRANCE * HUAWEI TECHNOLOGIES DUESSELDORF GMBH *

	TELECOM ITALIA SPA * SAMSUNG ELECTRONICS (UK) LIMITED ATOS SPAIN SA * HAMBURG PORT AUTHORITY * COMMISSARIAT A L ENERGIE ATOMIQUE ET AUX ENERGIES ALTERNATIVES * ETHNIKO KENTRO EREVNAS KAI TECHNOLOGIKIS ANAPTYXIS * MOBICS TELECOMMUNICATION AND CONSULTING SERVICES SA * REAL WIRELESS LIMITED NOMOR RESEARCH GMBH * TECHNISCHE UNIVERSITAET KAISERSLAUTERN *
Funding Source	H2020 (5G-PPP)
Funding	€ 7,681,088.75
Start / End	01/07/2017 - 30/06/2019
5G Classification Terms	Standardisation, architecture, NFV, Network Slicing, Network Automation,
Weblink	https://5g-ppp.eu/5g-monarch/
Description (containing objectives, potential outcomes)	The expected diversity of services, use cases, and applications in 5G requires a flexible, adaptable, and programmable architecture. While this has been addressed in 5G-PPP Phase 1 at a conceptual level, it must be brought into practice in Phase 2, taking into account progress in Standards and providing experimental results.

Project Title	BT Huawei Research collaboration in 5G network slicing
Lead Organisation	**Huawei**
Partners	BT
Funding Source	N/A
Funding	N/A
Start / End	N/A
5G Classification Terms	Network Slicing, mmWave
Weblink	http://home.bt.com/tech-gadgets/future-tech/bt-and-huawei-research-5g-network-slicing-11364158147163
Description (containing objectives, potential	The trials will focus on the technology enablers for 5G including mmWave radio and convergence, as well as potential commercial services including ultrafast mobile

outcomes)	broadband, mission-critical services and the 'Internet of Things' (IoT).

Project Title	Teams at Huawei's Wireless X Labs and the University of Edinburgh's new Bayes Centre will focus on devices that operate using 5G networks
Lead Organisation	**Huawei**
Partners	University of Edinburgh, Huawei
Funding Source	N/A
Funding	N/A
Start / End	N/A
5G Classification Terms	Ai/ smart robotics
Weblink	https://www.ed.ac.uk/informatics/news-events/stories/huawei-5g-deal-focuses-on-ai-and-smart-robotics
Description (containing objectives, potential outcomes)	Edinburgh experts and global telecoms firm Huawei are to collaborate on the development of artificially intelligent robots supported by next-generation wireless networks.

Project Title	5G Innovation Centre at the University of Surrey - testing and measurement expertise
Lead Organisation	**Aircom**
Partners	University of Surrey
Funding Source	N/A
Funding	N/A
Start / End	N/A
5G Classification Terms	System Integration / Validation / Simulation
Weblink	https://www.realwire.com/releases/AIRCOM-joins-Consortium-to-Support-University-of-Surrey-with-5G-Project
Description (containing objectives,	AIRCOM International, the leading independent network design and optimisation software and solutions provider, has revealed that it is a member of a new consortium that is investing over

potential outcomes)	£30 million to deliver a specialised 5G Innovation Centre at Surrey University. AIRCOM and 12 other telecoms industry leaders will provide their expertise in the provisioning and deployment of network engineering.

Project Title	Cobham demonstrates new 5G testing capabilities at Mobile World Congress
Lead Organisation	**Cobham**
Partners	
Funding Source	
Funding	
Start / End	N/A
5G Classification Terms	System Integration / Validation / Simulation
Weblink	http://cobhamwireless.com/press-and-events/press-releases/cobham-demonstrates-new-5g-testing-capabilities-mobile-world-congress/
Description (containing objectives, potential outcomes)	Demonstrating the industry's first software-defined 5G user equipment (UE) simulator, based on Verizon's open 5G standard, which can test downlink throughput of 10Gbps.

Project Title	R&D Based out of the 5G Innovation Centre - University of Surrey
Lead Organisation	**Fujitsu**
Partners	R&D Based out of the 5G Innovation Centre - University of Surrey
Funding Source	
Funding	
Start / End	N/A
5G Classification Terms	Corporate R&D, MAC / RRM, Mobile Edge Computing (MEC),

Weblink	http://www.fujitsu.com/uk/about/local/corporate/subsidiaries/fle/aboutus/012.html http://www.fujitsu.com/uk/about/local/corporate/subsidiaries/fle/careers/fle2015072102.html
Description (containing objectives, potential outcomes)	Fujitsu's Future Networking Research Division: Focusing on innovation, engineering and standardization of network services and technologies, in support of Fujitsu's Human Centric Intelligent Society vision. 5G represents a key element of our research, with our dedicated team now based at the world's first research centre dedicated to 5G, the 5G Innovation Centre at the University of Surrey.

Project Title	5G Network Slice Performance
Lead Organisation	**mycomosi**
Partners	At the 5GIC, MYCOM OSI software is used to monitor end-to-end network performance of the 5GIC testbed
Funding Source	
Funding	
Start / End	N/A
5G Classification Terms	Network Slicing, RAN, NFV
Weblink	http://www.mycom-osi.com/5g
Description (containing objectives, potential outcomes)	MYCOM OSI participated in the Catalyst proof of concept '5G Service Operations: Closed Loop Assurance of 5G Network Slices' during TM Forum Live! 2017 in Nice.

Project Title	5G Research Team at the Centre for Telecommunications Research
Lead Organisation	**Advanced Wireless Technology Group**
Partners	King's College
Funding Source	
Funding	
Start / End	N/A
5G Classification Terms	Infrastructure
Weblink	http://awtg.co.uk/services/m2m-iot/

Description (containing objectives, potential outcomes)	AWTG is actively working on 5G use cases and infrastructure requirements in collaboration with the 5G Research Team at the Centre for Telecommunications Research, King's College, London.

Project Title	Flex 5G ware: Flexible and efficient hardware/software platforms for 5G network elements and devices
Lead Organisation	INTEL DEUTSCHLAND GMBH *
Partners	ALCATEL-LUCENT DEUTSCHLAND AG * COMMISSARIAT A L ENERGIE ATOMIQUE ET AUX ENERGIES ALTERNATIVES * CONSORZIO NAZIONALE INTERUNIVERSITARIO PER LE TELECOMUNICAZIONI * CENTRE TECNOLOGIC DE TELECOMUNICACIONS DE CATALUNYA * ERICSSON AB * FRAUNHOFER GESELLSCHAFT ZUR FOERDERUNG DER ANGEWANDTEN FORSCHUNG E.V. * IMINDS * INTERUNIVERSITAIR MICRO-ELECTRONICA CENTRUM * KATHOLIEKE UNIVERSITEIT LEUVEN * NEC EUROPE LTD SEQUANS COMMUNICATIONS SA * TELECOM ITALIA SPA * TECNOLOGIAS SERVICIOS TELEMATICOS Y SISTEMAS S.A. * UNIVERSIDAD CARLOS III DE MADRID * UNIVERSITA DI PISA * Teknologian tutkimuskeskus VTT Oy * WINGS ICT SOLUTIONS INFORMATION & COMMUNICATION TECHNOLOGIES EPE *
Funding Source	H2020 (5G-PPP)
Funding	€ 7,993,585.25
Start / End	01/07/2015 - 30/06/2017
5G Classification Terms	Infrastructure, energy efficiency
Weblink	https://5g-ppp.eu/flex5gware/
Description (containing objectives, potential outcomes)	The overall objective of Flex5Gware is to deliver highly reconfigurable hardware (HW) platforms together with HW-agnostic software (SW) platforms targeting both network elements and devices and taking into account increased capacity, reduced energy footprint, as well as scalability and modularity, to enable a smooth transition from 4G mobile wireless systems to 5G.

Project Title	5G Tango:5G Development and Validation Platform for global Industry – specific Network Services and Apps
Lead Organisation	ATOS *
Partners	NEC ALTICE LABS SA * NOKIA BELL LABS FRANCE * TELEFONICA INVESTIGACION Y DESARROLLO SA * HUAWEI TECHNOLOGIES (IRELAND) CO LIMITED * UNIVERSITAET PADERBORN * "NATIONAL CENTER FOR SCIENTIFIC RESEARCH ""DEMOKRITOS""" * CENTRE TECNOLOGIC DE TELECOMUNICACIONS DE CATALUNYA * INTERUNIVERSITAIR MICRO-ELECTRONICA CENTRUM * WEIDMULLER INTERFACE GMBH & CO KG * NUROGAMES GMBH * SYNELIXIS LYSEIS PLIROFORIKIS AUTOMATISMOU & TILEPIKOINONION ANONIMI ETAIRIA * UNIVERSITY OF PIRAEUS RESEARCH CENTER * EASY GLOBAL MARKET SAS * UBITECH LIMITED * QUOBIS NETWORKS SL *
Funding Source	EU (5G-PPP)
Funding	€ 6,983,507
Start / End	01/06/2017 - 30/11/2019
5G Classification Terms	SDN, NFV, IoT- Industry 4.0, Media (AR/VR)
Weblink	https://5gtango.eu/
Description (containing objectives, potential outcomes)	5GTANGO puts forth the flexible programmability of 5G networks with i) a NFV-enabled Service Development Kit (SDK), ii) a Store with advanced validation and verification mechanisms for VNFs/Network Services qualification (including 3rd party contributions) and iii) a modular Service Platform in order to bridge the gap between business needs and network operational management systems. We propose an integrated vendor-independent platform where the outcome of the development kit, that is a packaged NFV forwarding graph, is automatically tested and validated in the Store for their posterior deployment with a customizable orchestrator compatible with common existing Virtual Infrastructure Managers (VIM) and SDN controllers in the market. This end-to-end ecosystem for the agile development and deployment of services realises an extended NFV DevOps model between service developers, telecom

	operators and vertical industries, increasing operational efficiency, facilitating the implementation and validation of new services and accelerating the adoption of NFV technologies. 5GTANGO system will be demonstrated in two vertical pilots: advanced Manufacturing and immersive Media. 5GTANGO will actively promote collaboration and try to influence the SDOs most relevant for the project such as ETSI NFV or IETF, as well as the key open source initiatives such as OSM and Open-O. It is also 5GTANGO's ambition to make key contributions to the 5G-PPP Programme, the targeted KPIs and commits to work with its peer 5G-PPP projects.

Project Title	5G Transformer: 5G Mobile Transport Platform for Verticals
Lead Organisation	UNIVERSIDAD CARLOS III DE MADRID *
Partners	NEC EUROPE LTD ERICSSON TELECOMUNICAZIONI * ATOS SPAIN SA * NOKIA SOLUTIONS AND NETWORKS GMBH &CO KG * INTERDIGITAL EUROPE LTD TELEFONICA INVESTIGACION Y DESARROLLO SA * ORANGE SA * CENTRO RICERCHE FIAT SCPA * AYUNTAMIENTO DE MADRID * B-COM * NEXTWORKS * MIRANTIS POLAND SPOLKA Z OGRANICZONA ODPOWIEDZIALNOSCIA * CENTRE TECNOLOGIC DE TELECOMUNICACIONS DE CATALUNYA * POLITECNICO DI TORINO * EURECOM * SCUOLA SUPERIORE DI STUDI UNIVERSITARI E DI PERFEZIONAMENTO SANT'ANNA * INDUSTRIAL TECHNOLOGY RESEARCH INSTITUTE INCORPORATED *
Funding Source	EU (5G-PPP)
Funding	€ 7,985,582.50
Start / End	01/06/2017 - 30/11/2019
5G Classification Terms	SDN, NFV, Network Slicing, Network Automation, Automotive, IoT-Health, Media (AR/VR)
Weblink	http://5g-transformer.eu/
Description	The vision of the 5G-TRANSFORMER project is that Mobile

(containing objectives, potential outcomes)	Transport Networks shall transform from today's rigid interconnection solutions into an SDN/NFV-based 5G Mobile Transport and Computing Platform (MTP) able of simultaneously supporting an extremely diverse range of networking and computing requirements to meet in particular the specific needs of vertical industries. A new networking paradigm known as Network Slicing has emerged for 5G as the most promising approach to address this challenge by enabling per slice management of virtualized resources. 5G-TRANSFORMER aims to bring the "Network Slicing" paradigm into mobile transport networks by provisioning and managing MTP slices tailored to the needs of vertical industries. Specifically: automotive, healthcare and media. The technical approach is twofold: (1) Enable Vertical Industries to meet their service requirements within customised MTP slices; and (2) Aggregate and Federate transport networking and computing fabric, from the edge up to the core and cloud, to create and manage MTP slices throughout a federated virtualized infrastructure. The proposed solution defines three novel building blocks that will be developed and demonstrated integrating the aforementioned three vertical industries: (1) Vertical Slicer as the logical entry point (i.e., one stop shop) for verticals to support the creation of their respective transport slices in a short time-scale (in the order of minutes). (2) Service Orchestrator to orchestrate the federation of transport networking and computing resources from multiple domains and manage their allocation to slices. (3) Mobile Transport and Computing Platform as the underlying unified transport stratum for integrated fronthaul and backhaul networks.

Project Title	5G Essence:5G ESSENCE: Embedded Network Services for 5G Experiences
Lead Organisation	HELLENIC TELECOMMUNICATIONS ORGANISATION S.A. - OTE AE
Partners	NEC EUROPE LTD INTEL RESEARCH AND DEVELOPMENT IRELAND LIMITED * TriaGnoSys GmbH * ATOS SPAIN SA * PIETRZYK SLAWOMIR * WIND TRE SPA * ATHONET SRL * FUNDACIO PRIVADA I2CAT, INTERNET I INNOVACIO DIGITAL A CATALUNYA * FONDAZIONE BRUNO KESSLER * SMART MOBILE LABS GMBH *

	"NATIONAL CENTER FOR SCIENTIFIC RESEARCH ""DEMOKRITOS""" * CAPRITECH LIMITED BAPCO LBG UNIVERSITAT POLITECNICA DE CATALUNYA * THALES COMMUNICATIONS & SECURITY SAS * ITALTEL SPA * ORION INNOVATIONS PRIVATE COMPANY * UNIVERSIDAD DEL PAIS VASCO/ EUSKAL HERRIKO UNIBERTSITATEA * EIGHT BELLS LTD * MUNICIPALITY OF EGALEO *
Funding Source	EU (5G-PPP)
Funding	€ 7,978,272.50
Start / End	01/06/2017 - 30/11/2019
5G Classification Terms	MEC (Mobile Edge Computing), HetNet, Business Models
Weblink	http://www.5g-essence-h2020.eu/
Description (containing objectives, potential outcomes)	5G ESSENCE addresses the paradigms of Edge Cloud computing and Small Cell as a Service by fuelling the drivers and removing the barriers in the Small Cell market, forecasted to grow at an impressive pace up to 2020 and beyond and to play a key-role in the 5G ecosystem. 5G ESSENCE provides a highly flexible and scalable platform, able to support new business models and revenue streams by creating a neutral host market and reducing operational costs by providing new opportunities for ownership, deployment, operation and amortisation.

Project Title	5G Crosshaul:5G-Crosshaul: The 5G Integrated fronthaul/backhaul transport network
Lead Organisation	UNIVERSIDAD CARLOS III DE MADRID *
Partners	NEC EUROPE LTD ERICSSON AB * ERICSSON TELECOMUNICAZIONI * ATOS SPAIN SA * NOKIA SOLUTIONS AND NETWORKS GMBH &CO KG * INTERDIGITAL EUROPE LTD TELEFONICA INVESTIGACION Y DESARROLLO SA * TELECOM ITALIA SPA * ORANGE SA * VISIONA INGENIERIA DE PROYECTOS SL *

	E-BLINK * NEXTWORKS * CORE NETWORK DYNAMICS GMBH * TELNET REDES INTELIGENTES SA * FRAUNHOFER GESELLSCHAFT ZUR FOERDERUNG DER ANGEWANDTEN FORSCHUNG E.V. * CENTRE TECNOLOGIC DE TELECOMUNICACIONS DE CATALUNYA * FONDAZIONE BRUNO KESSLER * CREATE-NET (CENTER FOR RESEARCH AND TELECOMMUNICATION EXPERIMENTATION FOR NETWORKED COMMUNITIES) * POLITECNICO DI TORINO * LUNDS UNIVERSITET * INDUSTRIAL TECHNOLOGY RESEARCH INSTITUTE INCORPORATED *
Funding Source	H2020 (5G-PPP)
Funding	€ 7,942,521
Start / End	01/07.2015 - 31/12/2017
5G Classification Terms	SDN, NFV, HetNets, MEC, mmWave, FWA
Weblink	http://5g-crosshaul.eu/
Description (containing objectives, potential outcomes)	The 5G-Crosshaul project aims at developing a 5G integrated backhaul and fronthaul transport network enabling a flexible and software-defined reconfiguration of all networking elements in a multi-tenant and service-oriented unified management environment. The 5G-Crosshaul transport network envisioned will consist of high-capacity switches and heterogeneous transmission links (e.g., fibre or wireless optics, high-capacity copper, mmWave) interconnecting Remote Radio Heads, 5GPoAs (e.g., macro and small cells), cloud-processing units (mini data centres), and points-of-presence of the core networks of one or multiple service providers. This transport network will flexibly interconnect distributed 5G radio access and core network functions, hosted on in-network cloud nodes, through the implementation of: (i) a control infrastructure using a unified, abstract network model for control plane integration (5G-Crosshaul Control Infrastructure, XCI); (ii) a unified data plane encompassing innovative high-capacity transmission technologies and novel deterministic-latency switch architectures (5G-Crosshaul Packet Forwarding Element, XFE).

Project Title	Coherent: Coordinated control and spectrum management for 5G heterogeneous radio access networks
Lead Organisation	Teknologian tutkimuskeskus VTT Oy

Partners	EURECOM * FONDAZIONE BRUNO KESSLER * CREATE-NET (CENTER FOR RESEARCH AND TELECOMMUNICATION EXPERIMENTATION FOR NETWORKED COMMUNITIES) * AALTO KORKEAKOULUSAATIO SR * RISE SICS AG * EUROPEAN CENTER FOR INFORMATION AND COMMUNICATION TECHNOLOGIES GMBH * THALES COMMUNICATIONS & SECURITY SAS * COMMAGILITY LIMITED UNIVERSITAET DUISBURG-ESSEN * HELLENIC TELECOMMUNICATIONS ORGANISATION S.A. - OTE AE (ORGANISMOS TILEPIKOINONION TIS ELLADOS OTE AE) * GOLDHAMER MARIANA * POLITECHNIKA POZNANSKA * INEA SPOLKA AKCYJNA * FAIRSPECTRUM OY * TRAVELPING GMBH *
Funding Source	EU (5G-PPP)
Funding	€ 6,024,299
Start / End	01/07.2015 - 31/12/2017
5G Classification Terms	HetNets, SDN,
Weblink	https://5g-ppp.eu/coherent/
Description (containing objectives, potential outcomes)	The exponential growth of mobile traffic, drastically increasing of network complexity, and the strong need for inter-network coordination of wireless network resources call for breakthroughs in control, coordination and flexible spectrum management in 5G heterogeneous radio access networks. The COHERENT project aims to address these problems by researching, developing and validating a novel control framework for future mobile networks. The key innovation of COHERENT is to develop a unified programmable control framework to coordinate the underlying heterogeneous mobile networks as a whole. The COHERENT control framework has two unique features to deal with the insufficiency of current control solutions for inter-network coordination. First, theories and methods to abstract the low layer network states and behaviours of different underlying mobile networks are developed, which provides a simplified but sufficient abstracted network view for network-wide control and resource coordination. Network abstraction will significantly reduce the signalling overhead, making scalable network-wide control solutions feasible, and enable more flexible spectrum management, which are key for the success of 5G networks. Second, based on the abstracted network view, common interfaces and software-development kits will be developed to

	enable programmability in controlling and coordinating heterogeneous mobile networks. The programmable control will provide operators a flexible and cost efficient way to implement new control functions and thus to support new services. The innovative impact of the COHERENT project is in enabling a unified control and coordination framework for heterogeneous mobile networks by combining innovative approaches on abstraction of low layers in underlying mobile networks, software defined networking, and flexible spectrum management. COHERENT will build a true proof-of-concept prototype to demonstrate the applicability and benefits of its approach.

Project Title	Low latency Virtual Reality Over Wireless (LoVROW)
Lead Organisation	**Blu Wireless Technology**
Partners	N/A
Funding Source	InnovateUK
Funding	£69,693
Start / End	June 2017 - May 2018
5G Classification Terms	mmWave
Weblink	http://gtr.ukri.org/projects?ref=132835
Description (containing objectives, potential outcomes)	The project will develop a technology that combines low latency video compression combined with an appropriate error correction technology that provides a robust streaming of real time virtual reality pixel stream over WiGig wireless at data rates up to 8Gbps. This will be demonstrated in principle and practice using a combination of software and FPGAs at lower rates/video resolutions in order to find the optimum design and sweet sport; for compression, error correction and low latency.

Project Title	Research and innovation partnership between Keysight and University of Bristol
Lead Organisation	**Keysight**
Partners	University of Bristol
Funding Source	N/A

Funding	N/A
Start / End	N/A
5G Classification Terms	mmWave
Weblink	https://5g.co.uk/news/university-of-bristol-teams-keysight-technologies-for-5g-research/4030/
Description (containing objectives, potential outcomes)	The two organisations will be particularly focused on trying to understand the nuances of millimetre-wave frequencies, using Keysight's millimetre-wave channel sounding hardware and software and the University of Bristol's advanced antenna and ray-tracing technologies to explore these frequencies in a test environment.

Project Title	Global 5G:Global vision, standardisation & stakeholder engagement in 5G
Lead Organisation	Trust-IT Services Ltd.
Partners	AALTO KORKEAKOULUSAATIO SR * IDC ITALIA SRL * INNO TSD *
Funding Source	EU (5G-PPP)
Funding	€ 895,000
Start / End	01/07/2017 - 31/12/2019
5G Classification Terms	Other
Weblink	https://www.global5g.org/
Description (containing objectives, potential outcomes)	A Collaboration web platform will showcase & monitor EU & international initiatives and joint R&I programmes with regard to 5G capabilities, standardisation, verticals, & related spectrum. Global5G.org analyses the sustainability strategies and identifies new business models, considering also private & public investments through pragmatic engagement drivers. Global5G.org will report on research findings taken to standardisation, testing validation to market uptake with a close eye on the vertical markets selected and mapping them into the right stakeholder groups.

Project Title	Spectrum Auction Strategy
Lead Organisation	**Ofcom**

Partners	
Funding Source	
Funding	
Start / End	
5G Classification Terms	Other
Weblink	https://www.ofcom.org.uk/__data/assets/pdf_file/0021/97023/5G-update-08022017.pdf
Description (containing objectives, potential outcomes)	An overview of the international process that has led to the identification of appropriate bands to meet the 5G requirements and provides an update on our programme of work with regards to these bands.

Four: UK local government activities in 5G

Project Title	5G Testbed
Lead Organisation	**Basingstoke City Council**
Partners	Enterprise M3, North Hampshire Hospital
Funding Source	Enterprise M3
5G Classification Terms	Testbed
Weblink	http://www.basingstokeobserver.co.uk/new-5g-test-bed-puts-basingstoke-at-the-forefront-of-technology

Description (containing objectives, potential outcomes)	The test bed, at the Innovation Centre in Basing View, was launched on Wednesday last week at the Ark Conference Centre at Basingstoke and North Hampshire Hospital. It brings together Enterprise M3, whose growth fund provided the investment, expertise from the University of Surrey's 5G Innovation Centre, and the borough council. The test bed will be directly connected to the University's £75million research and development facility for 5G.

Project Title	Digital Twin
Lead Organisation	**Bournemouth Borough Council**
Partners	5GIC, Met Office
Weblink	https://www.ordnancesurvey.co.uk/business-and-government/smart/5g.html
Description (containing objectives, potential outcomes)	5G Innovation Centre and the Met Office to build a digital twin. Assistance of University of Surrey Build a demonstration trial tool to help Government and network planners visualise how the rollout of the future 5G communications network can work.

Project Title	5G Testbed
Lead Organisation	**Milton Keynes Council**
Partners	Huawei, Samsung, Juniper, Tech Mahindra
5G Classification Terms	Smart City Infrastructure
Weblink	http://www.huawei.com/uk/news/uk/2017/huawei-signs-mou-with-milton-keynes-council-to-further-smart-city-innovation
Description (containing objectives, potential outcomes)	5G test bed, in partnership with Huawei on making it a Smart City with future connectivity. Submitted to testbed and trials program, application centred on CAV, testing 40 pods in June/July. Partnerships with Huawei, Samsung, Juniper, Tech Mahindra

Project Title	Plans for a 5G Testbed
Lead Organisation	**Nottingham City Council**
5G Classification Terms	Testbed
Weblink	https://www.midlandsengine.org/wp-content/uploads/Midlands-Engine-Vision-for-Growth.pdf
Description (containing objectives, potential outcomes)	There are plans in place for investment in infrastructure to create a 5G testbed - which is part of the areas long term digital strategy.

Project Title	City Fibre Contract
Lead Organisation	**Peterborough City Council**
Partners	CityFibre
5G Classification Terms	Infrastructure
Weblink	https://www.cityfibre.com/news/peterborough-city-council-connects-220-new-sites-onto-gigabit-city-network/
Description (containing objectives, potential outcomes)	Gigabit City Network for improved CCTV and Wi-Fi, creates the map for future 5G small cell locations.

Project Title	New ultrafast fibre broadband service as part of a deal between the local council and gigabit provider CityFibre.
Lead Organisation	**Southend-on-Sea Borough Council**
Partners	CityFibre
Funding Source	**Southend-on-Sea Borough Council**
Funding	£3.4m
5G Classification Terms	Infrastructure
Weblink	https://www.cable.co.uk/news/southend-using-dark-fibre-to-bring-ultrafast-broadband-to-public-buildings-700001412/
Description (containing objectives, potential outcomes)	CityFibre has been selected by Southend-on-Sea Borough Council to supply a 50km dark fibre network that will connect 120 key public sector sites throughout the town. As a Gigabit City, Southend will experience the benefits enjoyed by other CityFibre project cities. This infrastructure will enable the Council to deliver cost-effective and efficient digital public sector services, whilst catalysing business growth and inward investment. Mobile masts can be connected to the network to support upgrades to 4G and 5G services, and ultimately the network can provide a backbone for future deployments.

Project Title	Broadband Fibre upgrade
Lead Organisation	**Worcestershire County Council**
Weblink	http://www.superfastworcestershire.com/news/article/135/double-boost-for-worcestershire-households-and-businesses-wanting-to-get-their-broadband-up-to-speed
Description (containing objectives, potential outcomes)	Worcestershire County Council today announced two new schemes designed to help even more of the county's households and businesses to get high-speed fibre broadband. The first is a co-funding initiative, where the costs of deploying the

	expensive infrastructure is shared between the County Council, Openreach and local residents wanting to upgrade. Meanwhile, local firms wanting to improve their broadband speeds can apply for one of the County Council's new business broadband vouchers to help them with the cost of upgrading.

Project Title	City-wide full-fibre infrastructure project
Lead Organisation	CityFibre
Partners	City of York Council
5G Classification Terms	Infrastructure
Weblink	https://www.yorkshirepost.co.uk/news/historic-york-is-helping-support-uk-as-a-global-digital-leader-1-8750068 https://www.cityfibre.com/gigabit-cities/york/
Description (containing objectives, potential outcomes)	One of the factors is 4G infrastructure and ultrafast fibre connectivity with CityFibre The council want the town to be a smart city and has been identified as a Digital hotspot by a study done by Vodafone

Project Title	Digital Greenwich - smart city partnership with 5GIC
Lead Organisation	**Greenwich London Borough Council**
Partners	5GIC
5G Classification Terms	Smart City Infrastructure
Weblink	https://www.surrey.ac.uk/mediacentre/press/2018/5g-innovation-centre-and-digital-greenwich-form-partnership-create-pioneering
Description (containing objectives, potential outcomes)	The partnership leverages world-class 5GIC research and innovation, and will provide the foundation for next generation digital technology, standards and services in a Smart city context University of Surrey's 5G Innovation Centre (5GIC) will provide the technological foundations on which Digital Greenwich can build test beds and trials leading to commercial Smart City solutions Digital Greenwich will host a 5G Smart City Incubator space for innovators and entrepreneurs to work on new technology that will link transport, mobility, logistics, energy, healthcare and education

Project Title	Harrow Council procurement framework
Lead Organisation	**Harrow London Borough Council**

5G Classification Terms	Other
Weblink	https://www.local.gov.uk/our-support/our-improvement-offer/case-studies/facilitating-next-generation-mobile-connectivity
Description (containing objectives, potential outcomes)	Harrow Council has created a procurement framework to help public bodies host the new small cell mobile infrastructure needed for the next generation of digital connectivity. This case study forms part of our digital experts' resource.

Project Title	24/7 Free Wi-Fi
Lead Organisation	**Kingston upon Thames London Borough Council**
5G Classification Terms	Infrastructure
Weblink	https://www.kingston.gov.uk/news/article/677/kingston_becomes_first_in_the_capital_to_launch_free_247_wifi
Description (containing objectives, potential outcomes)	Kingston Council is delighted to announce the rollout of 24/7 free Wi-Fi, now live in Kingston's Ancient Market Place and New Malden High Street. The rollout follows an agreement with the UK communications infrastructure company Arqiva, to improve connectivity in the borough's district centres and ensure that Kingston is ready for the advent of 5G.

Project Title	London Borough Small Cell Rollout
Lead Organisation	Arqiva
Partners	Numerous London Local Councils
5G Classification Terms	Infrastructure
Weblink	https://5g.co.uk/news/5g-small-cells-lambeth-lamp-posts/4196/
Description (containing objectives, potential outcomes)	Arqiva now has exclusive access rights to approximately 15,000 lamp posts across The London Borough of Lambeth, making it the twelfth such Borough concession in the UK capital following on from Barnet, Brent, Camden, Hammersmith & Fulham, Haringey, Harrow, Hounslow, Islington, Merton, Richmond upon Thames and Wandsworth, Waltham Forest, Lambeth.

Project Title	Wireless Infrastructure Group (WIG) and O_2 have partnered to launch the UK's first fibre-connected small cell network
Lead Organisation	WIG
Partners	WIG, O_2, **City of Aberdeen**
5G Classification	Infrastructure

Terms	
Weblink	http://www.wirelessinfrastructure.co.uk/city-of-aberdeen-paves-the-way-for-5g/
Description (containing objectives, potential outcomes)	WIG's new wireless infrastructure uses a network of small cells attached to lamp-posts and traffic lights across Aberdeen's city centre. The small cells are connected back to a nearby hub using WIG's newly constructed fibre links which enable new network models that deliver faster and higher capacity mobile services. The infrastructure was designed, deployed and funded by WIG and is built to support all mobile operators as well as other wireless networks.

Project Title	The installation of a 150km fibre optic network across Scotland's capital, the result of collaboration between CityFibre and local provider Commsworld
Lead Organisation	**Edinburgh City Council**
Partners	CityFibre, Commsworld, intechnologyWiFi
Weblink	http://www.cityam.com/256356/titanic-struggle-between-mobile-data-allowance-and-user
Description (containing objectives, potential outcomes)	For visitors and residents alike, the installation of the UK's largest Gigabit network has also paved the way for the introduction of free public Wi-Fi across the city centre. A 10-year Wi-Fi concession, agreed with intechnologyWiFi in early 2016, has delivered blanket coverage across the city centre since the end of November. By providing access to Council-owned street furniture, the partnership has also enabled intechnologyWiFi to boost existing 4G mobile capacity and lay the groundwork for the next generation of 5G mobile data.

Project Title	Test bed - Mobile Innovation Living Lab (MILL)
Lead Organisation	**Dundee City Council**
Funding	£1.4m
5G Classification Terms	Infrastructure - groundwork for future 5G networks
Weblink	https://www.dundeecity.gov.uk/news/article?article_ref=3016
Description (containing objectives, potential outcomes)	DUNDEE is set to lead the way in some of the most innovative technology on the planet as the "internet of things" becomes an everyday reality. By providing a smart infrastructure network across the city, individuals and businesses will have access to superfast broadband and future 5G services.

Project Title	£38m for Newport foundry to make new technology behind 5G
Lead Organisation	**Newport Council**
Partners	Rhondda Cynon Taff, Bridgend, Vale of Glamorgan, Merthyr Tydfil, Caerphilly, Monmouthshire, Blaenau Gwent, Torfaen, Newport, Cardiff.
Funding Source	Government & Private Investment
Funding	£38m
5G Classification Terms	Infrastructure
Weblink	http://www.bbc.co.uk/news/uk-wales-south-east-wales-39837876
Description (containing objectives, potential outcomes)	Funding of nearly £38m has been announced for a facility to make compound semiconductors - a new technology behind robotics, 5G and driverless cars.

Project Title	5G Test-bed plans after £1.3 billion Swansea Bay city deal
Lead Organisation	Swansea Bay City Region
Partners	Carmarthenshire, Neath Port Talbot, Pembrokeshire and Swansea
Funding Source	Government & Private Investment
Funding	£1.3B
5G Classification Terms	Investment in innovation
Weblink	http://www.bbc.co.uk/news/uk-wales-politics-39321953
Description (containing objectives, potential outcomes)	The ambition for the bay area to be a test-bed for 5G technology is realised, then we can imagine a whole raft of other industries developing. Applications for other technology including driverless cars prototypes.

Project Title	Street Furniture Mapping
Lead Organisation	**Blaenau Gwent County Borough Council**
5G Classification Terms	Other - Mapping Project
Weblink	*Wales Local Study - Innovation Point
Description (containing objectives, potential	The purpose of this exercise was to determine the extent to with the existing

outcomes)	infrastructure could support the deployment of a local 5G network if it were to be proposed. This activity also goes hand in hand with wider planned activities, including a significant investment in a Technology Park through the newly announced Tech Valleys initiative. Delivering intelligent, integrated infrastructure that increases the value of rail services for providers and end users is key to human-centred design that influences customer journey preferences. Using 5G to trial ideas and technologies from other sectors will enhance the 'intelligent train' capability and undoubtedly lead to better interconnections between transport modes.

Project Title	5G Terrestrial & Satellite Network infrastructure Test bed
Lead Organisation	**Buckinghamshire Thames Valley**
Partners	SatApps
5G Classification Terms	Testbed
Weblink	https://sa.catapult.org.uk/our-opportunities/opportunities/5g-terrestrial-satellite-network-infrastructure-test-bed/
Description (containing objectives, potential outcomes)	As a joint funded venture between the Buckinghamshire Thames Valley Local Enterprise Partnership (BTVLEP) and the Satellite Applications Catapult, we have agreed to establish a 5G Step out Centre (SoC) focused on resilient communications and ubiquitous Internet of things (IoT). At the heart of Buckinghamshire, the centre will be located at Westcott Venture Park this new facility will give hardware, software, platform and applications developers' access to the latest generation of networking equipment without the need to invest in expensive infrastructure. This will allow them to rapidly prototype and commission new services and applications under representative real-world conditions ahead of market rollout. Westcott will be developed as an inherent part of a 5G testbed ecosystem.

Project Title	Brighton Test-Bed
Lead Organisation	**Coast to Capital - LEP**
Partners	Digital Catapult, Wired Sussex, University of Brighton, Coast to Capital LEP
Funding Source	Government Grant
Funding	£1.2m
5G Classification Terms	Testbed
Weblink	http://www.coast2capital.org.uk/media-centre/press-releases/a-national-5g-testbed-for-small-businesses--to-be-located-in-brighton.html
Description	A state of the art testbed to help small, innovative businesses across

(containing objectives, potential outcomes)	the UK develop new products and services that can benefit from 5G technologies is to be based in Brighton. 5G, a significant upgrade on current 4G mobile connectivity, is due to be rolled out across the UK from 2020 and will provide much faster, more stable connectivity and support the development of place-based technologies like driverless cars and connected smart cities.

Project Title	Test Bed - Metro Trials
Lead Organisation	**North East LEP**
Partners	The North East Combined Authority (NECA), the North East Local Enterprise Partnership (LEP), Nexus, the Digital Catapult Centre and the University of Surrey's 5G Innovation Centre, Tyne and Wear Metro.
5G Classification Terms	Testbed
Weblink	https://www.nelep.co.uk/news/north-east-bid-national-testbed-5g-trial/
Description (containing objectives, potential outcomes)	The North East Combined Authority (NECA), the North East Local Enterprise Partnership (LEP), Nexus, the Digital Catapult Centre and the University of Surrey's 5G Innovation Centre have joined forces through a memorandum of understanding to develop a plan to provide mobile phone operators and technology companies with the environment they need to test out how the next generation of mobile and wireless technology can improve the delivery of a wide range of services to people and businesses.

Project Title	5G Test bed
Lead Organisation	**Worcestershire**
Partners	University of Surrey's 5G Innovation Centre (5GIC), QinetiQ, Worcester Bosch and Yamazaki Mazak
5G Classification Terms	Testbed
Weblink	http://www.wlep.co.uk/worcestershire-set-lead-way-implementing-5g-applications-businesses/
Description (containing objectives, potential outcomes)	Worcestershire Local Enterprise Partnership (LEP) has announced plans to build the UK's first 5G test bed in partnership with the University of Surrey's 5G Innovation Centre (5GIC).

Project Title	5G RuralFirst: Rural Coverage and Dynamic Spectrum Access Testbed and Trial
Lead Organisation	Cisco
Partners	University of Strathclyde BBC University of Surrey Scottish Future Trust Agri-Epi Datavita Zeetta Microsoft Parallel Wireless Lime Microsystems pureLifi University of Edinburgh Heriot-Watt University Fairspectrum Nominet Telinet BT Faose Telecom/SHEFA Milkalyser Kingshay Afimilk Soil Essentials Hyperconnections CENSIS Stream Technologies Power Networks Demonstration Centre (PNDC) Cloudnet Orkney Island Council Broadway Partners
Funding Source	Government & Private sector grant (DCMS)
Funding	£4.3m
Start / End	April 2018 – March 2019
5G Classification Terms	Spectrum Sharing, Agriculture, Network Slicing, Media (AR/VR), IoT - Smart Cities
Weblink	https://www.5gruralfirst.org/
Description (containing objectives, potential outcomes)	Will deliver testbeds and trials to exploit 5G benefits for rural communities and industries like agriculture, broadcasting, and utilities, to address the challenges of and build the business case for 5G rural deployment. Key use cases: - Broadcast radio delivered over 5G with the BBC – the BBC believes internet-based delivery will become increasingly

	important to broadcasting. It will use the 5G testbed on Orkney to trial the capabilities of 5G to deliver traditional radio and new forms of BBC audio content over these new technologies. - Smart farming in partnership with Agri-EPI Centre – 72% of the UK's area is utilised for agricultural production, and the agri-food sector is an important contributor to UK GVA (over £112B per annum) . The trial will help provide significant opportunities to transform UK agriculture into a smart, high-tech industry, through innovations in sensors & remote diagnostics, data collection, UAVs (drones), wider precision farming techniques and autonomous vehicles. - IoT in Utilities and Environment Management – Electrical utilities and energy providers (wind, wave and solar), water companies, environmental monitoring, oil and gas industries – all have requirements for both general reliable data communications alongside low bit-rate, but high reliability and high security data communications for IoT (internet of things) in very remote areas. This will be addressed via network slicing and network edge data aggregation for 5G networks, alongside coverage trials and investigation. Dynamic Shared Spectrum development and trial – this potentially disruptive work led by the University of Strathclyde and others seeks to demonstrate the applicability of dynamic and shared spectrum technologies for 5G communications in rural areas, coupled with the deployment of low cost software-defined radio technologies, both with the intention of lowering the cost of future rural 5G communications deployment and presenting the opportunity for network self-provisioning.

Project Title	Worcestershire 5G Consortium - Testbed and Trials
Lead Organisation	Worcestershire Local Enterprise Partnership
Partners	Worcestershire County Council, 5GIC at University of Surrey, AWTG, Huawei, O_2, BT Malvern Hills Science Park. Worcester Bosch Yamazaki Mazak QinetiQ.
Funding Source	Government & Private sector grant
Funding **Start / End**	£4.8m April 2018 – March 2019
5G Classification Terms	MEC (Mobile Edge Computing), IoT - Industry 4.0, Security, Media (AR/VR)
Weblink	https://www.gov.uk/government/news/25m-for-5g-projects-on-the-

	anniversary-of-the-uks-digital-strategy
Description (containing objectives, potential outcomes)	A team of 5G and Industry 4.0 experts lead this project – working with Worcestershire LEP, the consortium comprises: Worcestershire County Council, 5GIC at University of Surrey, AWTG, Huawei, O_2, BT and Malvern Hills Science Park. With local businesses Worcester Bosch, and Yamazaki Mazak it will focus on ways to increase industrial productivity through preventative and assisted maintenance using robotics, big data analytics and AR over 5G.

Project Title	Liverpool 5G Testbed
Lead Organisation	Sensor City
Partners	Blu Wireless Technology, AIMES, Inventya, DefProc, Digital Creativity in Disability, CGA Simulation, Liverpool City Council, RLBUHT, Liverpool University, Liverpool John Moore's University
Funding Source	Government & Private sector grant (DCMS)
Funding	£3.5m
Start / End	April 2018 - March 2019
5G Classification Terms	Media (AR/VR), IoT-Health, HetNets
Weblink	https://www.gov.uk/government/news/25m-for-5g-projects-on-the-anniversary-of-the-uks-digital-strategy
Description (containing objectives, potential outcomes)	Sensor City will lead a consortium made up of public sector health suppliers, the NHS, university researchers, local SMEs and a leading UK 5G technology vendor. Funded for one year in the first instance, the project will see high value technologies including low-cost open source 5G networks, artificial intelligence, virtual reality and IoT deployed across deprived communities in the Liverpool City Region test bed. The consortium will use this technology to reduce the digital divide, while measuring the impact on patient monitoring and support, management of loneliness in older adults, aid to independents living in the home and the facilitation of communication between hospitals and the community. A successful demonstration of a 5G testbed in health and social care will see the development of new, innovative and disruptive technologies that will help to bridge the digital divide in the UK, especially in deprived communities. 5G Wi-Fi will not only enable the development of new cost-effective products and services to address real needs and demand, but also bring huge social and economic benefits for the most vulnerable in

	society, while reducing the demand on hospital-based services.

Project Title	AutoAir: 5G Testbed for Connected and Autonomous Vehicles
Lead Organisation	Airspan Communications Ltd
Partners	University of Surrey, Dense Air Limited, McLaren Applied Technologies, Blu Wireless Technology Limited, Quortus Limited, Millbrook, Real Wireless, ARM, Cobham Wireless, Celestia Technologies.
Funding Source	Government & Private sector grant (DCMS)
Funding	£4.1m
Start / End	April 2018 – March 2019
5G Classification Terms	Automotive, mmWave, Small Cell, Network Slicing
Weblink	https://www.gov.uk/government/news/25m-for-5g-projects-on-the-anniversary-of-the-uks-digital-strategy
Description (containing objectives, potential outcomes)	AutoAir will aim to make 5G technologies available for the validation and development of Connected and Autonomous Vehicles (CAVs) at the UK's premiere vehicle proving ground at Millbrook. Fast travel speeds complicate cell-tower handoff, and autonomous vehicles will require more network bandwidth than is available currently. It will also investigate how these 5G connectivity solutions could be transferable to both road and rail transportation. The project is based on the accelerated development of 5G small cells operating in both licensed Sub 6 GHz and mmWave bands on a shared 'neutral host' platform which allows multiple public and private 5G operators to simultaneously use the same infrastructure using network slicing.

Project Title	5G Rural Integrated Testbed (5GRIT)
Lead Organisation	Quickline Communications
Partners	Cybermoor 5G Services Ltd, Broadway Partners, North Pennines AONB Partnership, Precision Decisions Ltd,

	WT Info Tech Private Ltd, Kingston University, Lancaster University, King's College London Blue Bear Systems Research Ltd.
Funding Source	Government & Private sector grant (DCMS)
Funding	£2.1m
Start / End	April 2018 – March 2019
5G Classification Terms	MAC/RRM, HetNets, Agriculture, Media (AR/VR)
Weblink	https://www.gov.uk/government/news/25m-for-5g-projects-on-the-anniversary-of-the-uks-digital-strategy
Description (containing objectives, potential outcomes)	5GRIT will be trialling innovative use of 5G technology across a range of rural applications, such as smart agriculture, tourism and connecting poorly-served communities, using shared spectrum in the TV bands and a mix of local ISPs and self-provision. The aim is to ultimately make high quality connectivity available across Cumbria, Northumberland, North Yorkshire, Lincolnshire, Inverness-shire, Perthshire and Monmouthshire. Here the consortium will develop 5G-ready AR apps for tourists and investigate how high-bandwidth wireless connectivity can increase food production in farming, including through use of AR and an unmanned aerial system.